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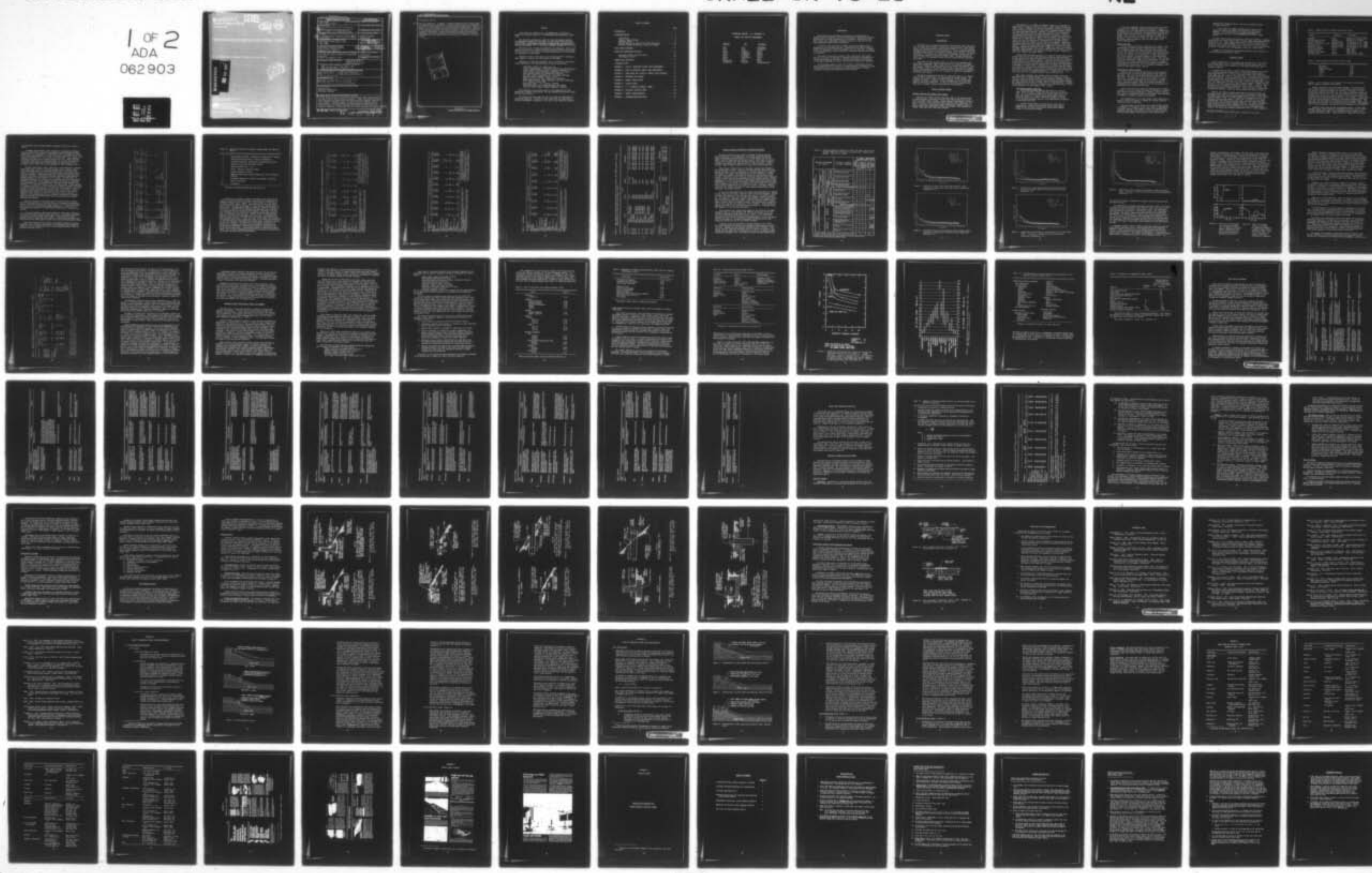

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A review of the literature on wastewater stabilization lagoon linings covering the work during the past 20 years is presented. Design, operating and maintenance experiences are presented for soil sealants, natural sealants, bentonite clays, chemical treatments, gunite, concrete, asphaltic compounds, plastics and elastomers. The characteristics of various materials, applicability to different wastes, construction techniques and details of installation techniques are presented. Installation costs for various materials and comparative CONT

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20. Abstract (cont'd)

COST

costs are summarized. A summary of reported seepage rates for various types of lining materials is presented. A survey of the 50 states was conducted to determine the requirements for liners and allowable seepage rates. Requirements are varied and depend upon the local soil conditions and the experiences of the regulatory agencies with various materials. The trend is toward more stringent requirements. Accepted design and installation procedures are summarized, and detailed drawings of installation techniques are presented. Recommendations of the manufacturers and installers of liners are also presented.

PREFACE

This report was prepared by E. Joe Middlebrooks, Catherine D. Perman, and Irving S. Dunn all of Middlebrooks and Associates, Logan, Utah.

The study was performed for the U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) and was funded under DA Project 4A762720 A896, Environmental Quality for Construction and Operation of Military Facilities; Task 02, Pollution Abatement Systems; Work Unit 004.

The final scope of study was defined by Mr. Sherwood C. Reed of USA CRREL and he served as technical monitor during the course of the study and his efforts in this regard contributed significantly to the successful completion of this report.

Technical review of this report was performed by Messrs. Sherwood C. Reed, Robert S. Sletten, and John Bouzoun of USA CRREL.

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Multiply	By	To obtain
inch	25.4	millimeter
inch	2.54	centimeter
foot	0.3048	meter
$yard^2$	0.8361274	$meter^2$
$foot^3$	0.02831685	$meter^3$
$yard^3$	0.764555	$meter^3$
gallon	0.003785412	$meter^3$
pound	453.6	gram
$pound/inch^2$	6894.757	pascal
$pound/foot^3$	16.01846	$kilogram/meter^3$

INTRODUCTION

Many difficulties have been encountered in the application of various types of materials as liners in wastewater stabilization lagoons. Difficulties have been pronounced in cold climates. Experiences have been varied, and considerable confusion exists as to the type of materials applicable under various conditions.

A review of the literature on lagoon liners and seepage rates is presented in the following sections. Experiences with various types of liners are described and observed seepage rates are reported. A summary of 50 state regulatory agency standards is presented and indicated trends are discussed.

The types of materials available, their properties, their applicability to various situations, recommended installation techniques and failure mechanisms are discussed. Detailed installation instructions and designs recommended by several installation companies are presented.

The following summary of the use of liners in wastewater stabilization lagoons should be of value to design engineers, reviewers of plans and specifications, and regulatory and planning personnel in making decisions concerning the protection of water quality.

LITERATURE REVIEW

Introduction

The need for a well-sealed wastewater stabilization lagoon has become part of modern lagoon design, construction and maintenance. The primary motive for sealing wastewater stabilization lagoons is to prevent seepage. Seepage has two effects on lagoon performance. First, seepage affects the treatment capabilities of the lagoon by causing fluctuations in the lagoon water depth. For consistent and sufficient treatment, lagoons require a constant water depth at a specified design depth. Second, seepage can cause pollution of groundwater which can have serious effects on groundwater uses.

Many types of lagoon liners exist, but all can be classified into three major categories. These categories are (1) synthetic and rubber liners, (2) earthen and cement liners, and (3) natural and chemical treatment sealers. Within each category also exists a wide variety of application characteristics. Each of the three liner categories and respective application characteristics will be discussed in detail in a subsequent section of this report.

Choosing the appropriate lining for a specific lagoon is a critical issue in lagoon design and in the improvement of seepage control. The criteria for lining a lagoon are highly dependent on the specific geographical location, on climate, on local hydrogeology and on materials found in the lagoon wastewater. In this review special attention has been given to design criteria established for cold climates.

Types of Lagoon Linings

Earthen, Concrete and Asphalt Type Linings

Concrete and earthen liners constituted some of the earliest types of lagoon sealers. Literature from the late fifties cited use of concrete to prevent lagoon seepage. Sewage lagoons in Melbourne, Australia, were built with a 2-in. thick unreinforced concrete liner (Parker et al., 1959). Wastewater stabilization ponds constructed in Austin, Texas, as outdoor pilot-plant experiments (Gloyna and Hermann, 1956; Hermann and Gloyna, 1958) were also lined with concrete.

Van Heuvelen et al. (1960) and Hopkins (1960) all recognized the significance of lagoon liners in a study of lagoon design for Missouri Basin States. Prevention of chemical groundwater pollution and maintenance of constant lagoon surface level were considered primary reasons for preventing lagoon seepage. Chemical contamination of groundwater from the detergents found in lagoon wastewater was a major concern. The seepage of biological pollutants was only a problem in infrequent geologic situations where the major surface formation consisted of fissured rock or coarse gravel. However, in most situations, removal of porous top soil and compaction of underlying soil provided adequate sealing for both the bottoms and the dikes of the lagoons. When excessive percolation was still a problem, increased hydraulic loading and removal of gravel and sand pockets were suggested as methods of partial sealing. Eventually wastewater solids clogged soil pores, and further decreased lagoon seepage. To assure a complete seal, bentonite clay and asphaltic coatings were cited as practical lagoon liners. Similar results were reported by Leisch (1976).

Benson (1962) described bentonite as a typical natural earth lagoon sealer because of its very high swelling and gelling characteristics. As with most earthen sealers, bentonite was found to seal most effectively when applied to an emptied lagoon. A precise application procedure was described using a 5-15 percent by volume mixture of bentonite with a loose silty soil, which was then spread over the lagoon and compacted to a thickness of several inches. Unfortunately, bentonite has been shown to be subject to piping and to diffusion through soil, sands and gravels with large pore channels. Lagoon site soil characteristics should therefore be a criterion in choosing bentonite for a lagoon sealant. The cited 1962 price for processed bentonite was $14-$20 per ton.

Edge (1967) suggested that asphalt liners provided a practical general solution to lagoon seepage. Three types of asphaltic construction were cited and consisted of hot-sprayed asphalt membranes, asphalt concrete (requires periodic cleaning), and prefabricated asphalt linings. The characteristics of each of these liners are impermeability, toughness, and durability in the presence of domestic and industrial wastes. A detailed description of each asphalt liner follows:

"<u>Hot-Sprayed Asphalt Membranes</u>

A hot-sprayed asphalt membrane developed as a low-cost canal lining provides a highly effective continuous waterproof seal. It is a continuous blanket of asphalt cement about 1/4 inch thick placed by a regular asphalt distributor with the spray bar offset to one side. The heated asphalt is sprayed on the prepared subgrade, usually in two applications to insure a continuous water seal.

A special blown asphalt is preferred for this type of construction. However, in some areas satisfactory asphalt membranes can be formed using regular paving grade asphalt cement, 40-50 penetration grade.

An earth or aggregate cover is needed on the side slopes to protect the lining from oxidation and physical damage. A thickness of 6 to 8 inches should be sufficient. Sedimentation and sludge that will eventually be deposited will provide sufficient cover from the bottom. The side slopes should not be steeper than 2:1 with a 3:1 slope preferred. If there is danger of erosion from wave action, the side cover should be an erosion resistant material such as local gravel or an asphalt-aggregate mix.

Asphalt Concrete

Hot-mix asphalt concrete is especially well suited to the construction of sewage and waste stabilization lagoons. Its use is desirable when operating conditions make it necessary for periodic cleaning of a storage facility by equipment and trucks. The asphalt concrete is similar to that used for highway surface courses, but it should have a higher percentage (6.5 to 9.5 percent) of asphalt cement of a low penetration grade and a higher percentage of mineral filler. This insures a practically voidless lining that is impermeable to water when compacted. The asphalt concrete can be placed by a regular paving machine on a properly shaped and prepared subgrade with side slopes no steeper than 2:1. A compacted thickness of two inches is sufficient for most lagoons.

Prefabricated Asphalt Linings

Another type of lining recommended for severe operating conditions may be constructed using prefabricated asphaltic materials. They vary in thickness generally from 5/32 to 1/2 inch thick, in pieces 3 to 4 feet wide and usually 10 to 15 feet long. Some materials come in rolls similar to roofing rolls. The lining is fashioned by fitting pieces together to form a continuous lining. They may be joined together by overlapping and cementing together or by butting together and cementing batten strips over the seams.

Prior to placing the lining, the subgrade must be shaped, although it will not require the degree of compaction or smoothness needed for asphalt membranes or asphalt concrete linings. This type of lining lends itself to areas where conditions make it difficult to operate construction equipment.

The subgrade soil of all side slopes, where vegetation is likely to erupt and rupture or damage the linings, should be treated with soil sterilants.

The only need, in most cases, for a hard-surfaced lining, or pavement, in a lagoon is on the side slopes of embankments to prevent erosion. Both asphalt concrete and prefabricated asphaltic materials are suitable for use as slope protection. A hot-mix sand asphalt may be used for this purpose also.

Consideration should be given to the use of suitable locally available materials.

In all cases, the asphalt linings should extend up the slope well beyond the highest point where wave wash may be expected. It is good practice to extend the pavement all the way across the tops of the embankments and dikes." Edge (1967).*

Two pilot scale lagoons constructed to study the treatment of milking-parlor wastes in Salina, Kansas (Loehr and Ruf, 1968) were constructed in sandy-silty soil. These lagoons were partially sealed using 150 lbs of bentonite clay per lagoon spread on the lower half of the dikes and the bottom of each lagoon. The lagoons had a depth of 4 ft and a surface area of 400 ft^2. Without labor and equipment, total cost came to $100.

A summary of the earthen, concrete and asphaltic liners reported in the literature is presented in Table 1.

Synthetic Liners

Use of synthetics to line lagoons came into practice in the 1960's. In Minnesota (Ling, 1963) a lagoon treating chemical wastes with a capacity of 38,000 gal was lined with a 4-mil-thick polyethylene sheet to eliminate seepage.

In Broken Bow, Nebraska, a (Clark, 1965) fiber glass mat was installed to prevent erosion of sandy banks of a municipal sewage lagoon. Forty eight hundred ft^2 of 1/4-in. Gustin-Bacon heavy duty ultra-check fiber glass mat was placed at the water line. The installation procedure was clearly defined. After draining the lagoon, allowing two weeks of drying and compacting, the lagoon was cleared of weeds and then graded. A trench was dug (2 in. wide and 6 in. deep) to secure the upper edge of the mat. "T" shaped steel pins were used to secure the mat. Asphalt was then applied to the fiber glass mat at one gal/yd^2 at 200^oF. A 1/2-in. layer of gravel was then applied, followed by a second layer of asphalt. The securing trench was re-filled with soil. After two weeks of curing time, the pond was refilled. Costs for this procedure are shown in Table 2.

When an oil refinery company operating in Cook Inlet, Alaska, was faced with strict state water pollution control regulations concerning groundwater pollution, the refinery designs added a liner to their oxidation pond (Baker, 1970). The liner chosen was a combination of a polypropylene fiber mat and asphalt. This liner consisted of a non-woven polypropylene fiber which was sprayed with a cationic asphalt emulsion which formed a thin reinforced asphalt membrane. The fabric was made of oriented polypropylene fibers randomly placed on a supporting scrim. These fibers were fused during production to provide omni-directional support. The fibers are non-polar hydrocarbon that is readily wetted by

*Courtesy of Public Works Journal Corp., Ridgewood, New Jersey.

Table 1. Summary table of earthen and concrete liners.

Liner	Location	Reference
Concrete	Texas	Hermann and Gloyna (1958)
Unreinforced concrete	Autralia	Parker et al. (1959)
In situ compaction	Missouri Basin	Van Heuvelen et al. (1960)
Removal of porous top soil	Missouri Basin	Van Heuvelen et al. (1960)
Bentonite clay	Missouri Basin	Van Heuvelen et al. (1960)
Asphaltic coating	Missouri Basin	Van Heuvelen et al. (1960)
Hot-sprayed asphalt	U.S.A.	Edge (1967)
Asphalt concrete	U.S.A.	Edge (1967)
Prefabricated asphalt	U.S.A.	Edge (1967)
Bentonite clay	Kansas	Loehr and Ruf (1968)

Table 2. Fiber glass mat cost ($\$/yd^2$) (Clark, 1965).

Ditching	0.04
Fiber glass	0.35
Asphalt in place	0.60
T pins	0.12
Gravel	0.06
Total	$1.17

asphalt. In this fashion, the strength of the fabric reinforces the asphalt against compression and tension.

Design criteria for this liner were stringent. The liner had to have (1) good sealing qualities, (2) high flexibility and durability, (3) ability to withstand temperature to -40°F, (4) ability to resist abrasion and physical abuse from ice, (5) ready availability and ease of installation, and (6) low cost. The final design called for 11,850 yd^2 of fabric and 12,000 gal of asphalt emulsion. The strips of fabric were sewed with special polypropylene thread at a 3-in. overlap. Enough liner slack had to be permitted in design for the bottom configuration. This same liner was also used for an oxidation pond near Kenai, Alaska. The materials cost $\$3.26/yd^2$. The installation cost $\$2.94/yd^2$. Approximately half of the installation cost was due to the remoteness of the location.

Synthetic liners have become increasingly popular. A black polyethylene (Klock, 1971) (0.006 in. thickness) was used to line a 1,000-ft^3 pilot wastewater lagoon in the southwest U.S.A. because of its absolute sealing qualities. Vinyl-lined pilot lagoons were also used

in conjunction with rotating asbestos bio-disks in the U.S.A. (Boyle, 1971).

In Oregon (Public Works, 1971), lagoons at a high-use recreation area were lined with 10-mil-thick polyvinyl chloride furnished by Union Carbide Corp. in folded sheets. These sheets were overlapped and sealed with a water-proof adhesive. The PVC liner was covered with a 6-in. layer of pumice followed by a 1.5-in. layer of crushed rock. Later testing indicated that there was no seepage through the liner. Many references to specific application of lining materials are available but were not included in this review since little design and operating detail is provided (Staff, 1967, 1971, 1973; Abelishvili, 1972; Jacobson, 1972).

Thornton and Blackall (1976) conducted a field evaluation of plastic film liners used to protect petroleum storage areas in Canada. Seven petroleum storage areas in the Mackenzie-Delta area using artificial liners to enhance the spill retention capabilities of petroleum storage areas were studied. Polyurethane (20 mil), prestressed laminated polyethylene, and fiber reinforced polyurethane appeared to show promise as lining materials for the retention of oil spills. The importance of bedding preparation was stressed, and if the membrane had a low puncture resistance, the need for an adequate thickness of protective overburden was also emphasized. Exposed membranes invariably become damaged, and therefore it is extremely important that the installation of the membrane be conducted carefully. It was concluded that carefully chosen and properly installed plastic membranes can be effective and economical in the retention of spills from petroleum storage areas in the Arctic. Plastic membranes buried during the installation of the initial construction appear to offer promise as a means of protection from oil spills. If installed in existing systems, a more elaborate construction technique would be required and would probably make the installation of plastic membranes uneconomical.

Erosion of slopes of an aeration pond in Lenexa, Kansas (Staff, 1973) was prevented with a 6-ft-wide strip of a non-woven polypropylene fabric. The felt-like liner was sewed together on site and then sprayed with two coats of asbestos-filled asphalt emulsion. A final layer of fine gravel was applied at 25 lb/yd^2 and was then given a final coat of sealant.

A 2.5-acre synthetic rubber-lined industrial waste pond (Pelloquin, 1972) is being used by Imperial West Chemical Co. in Antioch, California, to convert U.S. Steel pickle liquor waste. Thirty-mil-thick Dupont Hypalon synthetic rubber was used because it resists physical abuse, and the effects of sun and weather as well as oil and acid contaminated fluids.

Kumar and Jedlicka (1973) provided an excellent summary of various synthetic liners and their properties. This information is presented in Tables 3a and 3b. Physical and structural information (Ewald, 1973) is provided in Tables 4 and 5.

Table 3a. Properties of commonly used lining materials (Kumar and Jedlicka, 1973).[a]

Property	Polyethylene Low Density	Polyethylene High Density	Polyvinyl Chloride	Chlorinated Polyethylene	Poly-propylene	Nylon	Butyl Rubber	Natural Rubber	Hypalon
Specific gravity	0.92-0.94	0.94-0.96	1.20-1.5	1.35-1.39	0.9-0.91	1.08-1.4	0.92-1.25	0.91-1.25	
Tensile strength, psi	1,300-2,500	2,400-4,800	3,500-10,000	1,800 min.	4,000-32,000	9,000-11,000	1,000-4,000	1,000-3,500	1,000-2,000
Elongation, %	200-800	10-650	60-200	375-575	40-400	250-550			
Shore "A" hardness							15-90	20-100	55-95
Operating temperature range, °F	-70 to 180	-70 to 240	-60 to 200	-40 to 200	-60 to 220	-60 to 380	-50 to 325	-70 to 250	-45 to 250
Resistance to acids	P-G	G	G-E	G-E	G-E	P			G
Resistance to bases	G-E	G-E	G-E	G-E	G-E	E			G-E
Resistance to oxygenated solvents	P-G	P-G	G	P					G
Resistance to aromatic and halogenated solvents	F	F	G	P	G	G	P	P	F
Resistance to aliphatic (petroleum) solvents	P-F	F-G	G	G	G	E	P	P	G
Water vapor permeability, per mils	3-14	1.8-2.2	3-18	0.040-0.048	0.25-1	0.09-1.0	0.15		2.0
Weatherability	P	P	G	E	P	F	G	F	E
Time to crack, hr.	900	300	No crack till 2,500 hr.	No effect till 4,000 hr.	100	1,200			
Time to chalk, hr.	No effect till 2,500 hr.	600	300	Ditto	600	No effect till 2,500 hr.			
Time to fade, hr.	300	300	100	Ditto	900	200			

Note: Data not shown were unavailable to the authors. P = Poor, F = Fair, G = Good, E = Excellent
ASTM test methods for various properties: specific gravity, D751; tensile strength, D97-61T; elongation, D412-61T or D882; Shore "A" hardness, D676-59T; water vapor permeability, E96-66.

[a]Courtesy of Chemical Engineering, New York, N.Y.

Table 3b. Selection criteria for synthetic liners (Kumar and Jedlicka, 1973).[a]

1	High tensile strength, flexibility, elongation w/o failure.
2	Resists abrasion, puncture, effects of wastewater.
3	Good weatherability, manufacturer guarantees long life.
4	Immune to bacterial and fungal attack.
5	Specific gravity (S) > 1.0.
6	Color: black (to resist UV light).
7	Minimum thickness, 20 mils.
8	Membrane should have uniform composition, free of physical defects.
9	Withstand temperature variation and ambient conditions.
10	Easily repairable.
11	Economical.

[a]Courtesy of Chemical Engineering, New York, N.Y.

A capability of synthetic rubber liners which is not directly applicable to the prevention of seepage, but which may be applicable to anaerobic lagoons in the future, is the effectiveness of these liners as floating covers (Rizzo, 1976). The floating cover is a non-rigid solution to the problem of covering the large areas of exposed water or other liquid. The impermeable sheet of synthetic rubber is attached to the berm of a reservoir and is designed with adequate slack to permit it to rise and fall as the liquid level changes. Floating covers compare favorably with the conventional systems utilizing wood, concrete, steel, or aluminum. Cost for wood, concrete, steel, or aluminum may range from \$4 to \$10/ft^2 depending on the location. Estimated service life may range from 25 to 75 years for these conventional type systems. The floating cover offers a lower first cost in the range of \$1.50 to \$2.50/ft^2 and when properly compounded these systems have an expected lifetime of from 25 to 50 years. In addition to the economic attraction, it appears that floating covers will provide savings in maintenance and may reduce the quantities of disinfecting chemicals required because of the assured protection. Several applications are described by Rizzo (1976), and he gives recommended procedures for preparation, manufacture, fabrication and installation specifications.

Table 4. Typical characteristics of various synthetic lining materials (Ewald, 1973).[b]

Base Reinforcement Fabric	Liners of Hypalon Membrane					Liners of EPDM Membrane			Liners of PVC Membrane		
Fabric count	16 x 8	16 x 8	22 x 11	14 x 14	12 x 12	-	-	-	22 x 11	38 x 38	21 x 21
Warp denier	100	100	210	440	840	-	-	-	210	210	840
Filling denier	210	210	420	440	840	-	-	-	420	210	840
Fiber	nylon	nylon	nylon	polyester	nylon	nylon	nylon	nylon	nylon	nylon	nylon
Weave	2/1 leno	2/1 leno	plain	plain	plain	-	-	-	plain	plain	plain
Weight, oz./sq. yd.	0.4	0.4	1.4	1.8	2.7	2	2	2	1.4	2.0	4.9
Membrane											
Coating thickness-Side A, mils	15	15[a]	14	14	14	-	-	-	5	4	6-1/2
Coating thickness-Side B, mils	15	15[a]	14	14	14	-	-	-	3	2	6-1/2
Total thickness, mils	30	45	28	28	28	30-34	44-46	61-65	10	10	18
Total weight, oz./sq. yd.	33	48	28-32[a]	30-32[a]	30[a]	-	-	-	10	9	18
Tensile strength, lbs./in.											
warp	75	120	120-165[a]	130[a]	280[a]	150	150	150	110	200	450
filling	75	120	120-165[a]	130[a]	280[a]	150	150	150	110	190	400
Elongation, % max.											
warp	23	23	-	-	-	30	30	30	-	-	-
filling	23	23	-	-	-	30	30	30	-	-	-
Tear strength, lbs. (tongue)											
warp	20	24	25-50[a]	10[a]	70[a]	25	25	25	40	11	96
filling	20	24	25-50[a]	10[a]	70[a]	25	25	25	40	11	80
Mullen hydrostatic	175	175	225-250[a]	200[a]	275[a]	200	200	200	500+	265	500

Notes:

"Warp" is the same as machine direction; "filling" is the same as cross-direction.

In addition to the above butyl rubber linings, similar linings of EPDM and butyl-rubber/EPDM blends are available.

Weights are without dip.

Unless noted, test methods of ASTM D-751 were used for thickness, total weight, tensile strength, elongation, tear strength, and Mullen hydrostatic data.

The list of PVC liners is far from complete enough to be representative. PVC liners should not be used unless covered with earth or water to prevent rapid weathering degradation.

CPE = chlorinated polyethylene; EPDM = ethylene-propylene-diene monomer; and PVC = polyvinyl chloride.

[a]This is a 5-ply material, film/scrim/film/scrim/film, with 3 plies of 15-mil-thick film and 2 plies of scrim.

[b]Courtesy of Chemical Engineering, New York, N.Y.

Table 4. Continued.

Base Reinforcement Fabric	Liners of Butyl Rubber Membrane										
Fabric count	18 x 17	18 x 17	22 x 14	22 x 14	22 x 14	22 x 14	22 x 14	12 x 12	12 x 12	21 x 21	22 x 21
Warp denier	210	210	210	210	210	210	210	840	840	840	840
Filling denier	210	210	420	420	420	420	420	840	840	840	840
Fiber	nylon	nylon	nylon	nylon	nylon	nylon	nylon	nylon	nylon	nylon	nylon
Weave	plain	plain	plain	plain	plain	plain	plain	plain	plain	plain	plain
Weight, oz./sq. yd.	1.0	1.0	1.4	1.4	1.4	1.4	1.4	2.7	2.7	4.8	4.9
Membrane											
Coating thickness-Side A, mils	-	-	-	-	-	-	-	-	-	5-1/2	-
Coating thickness-Side B, mils	-	-	-	-	-	-	-	-	-	5-1/2	-
Total thickness mils	17	20	20	-	32	45	62	32	62	16	45
Total weight, oz./sq./yd.	14.5	17.0	18.0	19.4	30	39.0	64	-	-	16	-
Tensile strength lbs./in.											
warp	85	85	100	112	100	100	100	225	-	450	225
filling	70	70	100	107	100	100	100	200	-	375	300
Elongation, % max.											
warp	30	35	20	20	30	30	30	30	-	-	30
filling	30	35	20	18	30	30	30	30	-	-	30
Tear strength lbs. (tongue)											
warp	5	5	8	12	12	12	12	50	55	40	50
filling	5	5	8	12	12	10-12	12	30	25	35	50
Mullen hydrostatic	100	125	125	185	180	185-190	200	350	-	500+	

Notes:

"Warp" is the same as machine direction; "filling" is the same as cross-direction.

In addition to the above butyl rubber linings, similar linings of EPDM and butyl-rubber/EPDM blends are available.

Weights are without dip.

Unless noted, test methods of ASTM D-751 were used for thickness, total weight, tensile strength, elongation, tear strength, and Mullen hydrostatic data.

The list of PVC liners is far from complete enough to be representative. PVC liners should not be used unless covered with earth or water to prevent rapid weathering degradation.

CPE = chlorinated polyethylene; EPDM = ethylene-propylene-diene monomer; and PVC = polyvinyl chloride.

[a]This is a 5-ply material, film/scrim/film/scrim/film, with 3 plies of 15-mil-thick film and 2 plies of scrim.

Table 4. Continued.

Base Reinforcement Fabric	Liners of Neoprene Membrane							Liners of CPE Membrane		
Fabric count	22 x 14	22 x 14	22 x 14	22 x 14	22 x 14	12 x 12	12 x 12	18 x 17	15 x 15	12 x 12
Warp denier	210	210	210	210	210	840	840	210d.	440d.	840d.
Filling denier	420	420	420	420	420	840	840	210d.	440d.	840d.
Fiber	nylon	nylon	nylon	nylon	nylon	nylon	nylon	nylon	polyester	nylon
Weave	plain	plain	plain	plain	plain	plain	plain	plain	plain	plain
Weight, oz./sq. yd.	1.4	1.4	1.4	1.4	1.4	2.7	2.7	1.0	1.8	2.7
Membrane										
Coating thickness-Side A, mils	-	-	-	-	-	-	-	4	14	14
Coating thickness-Side B, mils	-	-	-	-	-	-	-	4	14	14
Total thickness mils	20	32	32	35	45	32	45	8	28	28
Total weight, oz./sq. yd.	20	-	38	52	-	-	-	8.9[a]	30-32[a]	32-34[a]
Tensile strength, lbs./in.										
warp	100	100	100	100	100	225	225	258[a]	130[a]	365-420[a]
filling	100	100	100	100	100	200	200	202[a]	130[a]	365-420[a]
Elongation, % max.										
warp	30	30	30	30	30	30	30	-	-	-
filling	30	30	30	30	30	30	30	-	-	-
Tear strength (lbs./in.)										
warp	10	12	10	10	12	50	50	22[a]	10[a]	58-80[a]
filling	8	10	8	8	10	30	30	22[a]	10[a]	58-80[a]
Mullen hydrostatic	185	180	185	185	190	350	350	185[a]	200[a]	450-475[a]

Notes:

"Warp" is the same as machine direction; "filling" is the same as cross-direction.

In addition to the above butyl rubber linings, similar linings of EPDM and butyl-rubber/EPDM blends are available.

Weights are without dip.

Unless noted, test methods of ASTM D-751 were used for thickness, total weight, tensile strength, elongation, tear strength, and Mullen hydrostatic data.

The list of PVC liners is far from complete enough to be representative. PVC liners should not be used unless covered with earth or water to prevent rapid weathering degradation.

CPE = chlorinated polyethylene; EPDM = ethyl-propylene-diene monomer; and PVC = polyvinyl chloride.

[a]This data is in accordance with Federal Specification, CCC-T-191B, Methods 5041, 5100, 5134 and 5512.

Table 5. Some commercial reinforcements suitable for butyl rubber, CPE, EPDM, Hypalon, neoprene, polyethylene, PVC and other films (Ewald, 1973).[a]

Scrim

Count/inch	Yarn	Fiber	Weave	Treatment
16 x 8	Warp - 100 denier	nylon	2/1 leno	PVC, PVB or RFL/latex dipped
	Filling - 210 denier			
20 x 10	210 denier	nylon	2/1 leno	PVC, PVB or RFL/latex dipped
18 x 17	210 denier	nylon	plain	PVC, PVB or RFL/latex dipped
38 x 22	Warp - 100 denier	nylon	leno	PVC, PVB or RFL/latex dipped
	Filling - 210 denier	nylon		
22 x 11	Warp - 210 denier	nylon	plain	PVC, PVB or RFL/latex dipped
	Filling - 420 denier	nylon		
22 x 14	Warp - 210 denier	nylon	plain	PVC, PVB or RFL/latex dipped
	Filling - 420 denier	nylon		
15 x 15	440 denier	polyester	plain	PVC, PVB or RFL/latex dipped
36 x 10	Warp - 210 denier	nylon	leno	PVC, PVB or RFL/latex dipped
	Filling - 840 denier	nylon		
12 x 12	840 denier	nylon	plain	PVC, PVB or RFL/latex dipped
12 x 12	1000 denier	polyester	plain	PVC, PVB or RFL/latex dipped

Densely-Woven Fabrics

Count/inch	Yarn	Fiber	Treatment
21 x 21	840 denier	nylon	greige or heat set
22 x 21	840 denier	nylon	greige or heat set
26 x 13	Warp - 840 denier	nylon	greige or heat set
	Filling - 1680 denier		

[a]Courtesy of Chemical Engineering, New York, N.Y.

Natural Sealing and Chemical Treatment Mechanisms

The most interesting and complex techniques of lagoon sealing, either separately or in combination, are natural lagoon sealing and chemical treatment sealing (Thomas et al., 1966; Bhagat and Proctor, 1969). Natural lagoon sealing has been found to occur when the settled solids form a bottom layer that physically clogs soil pores. Chemical treatment has changed the chemical nature of the bottom soil to incur sealing. Table 6 shows classified soil types for sealing properties.

Infiltration characteristics of anaerobic lagoons were studied in New Zealand (Hills, 1976). Certain soil additives were added (bentonite, sodium carbonate, sodium triphosphate) to 12 pilot lagoons with varying pond depth, soil types, and compacted bottom soil thickness. A number of chemical and physical additives have been used for successful pond sealing. Monovalent cations (sodium, potassium, ammonium ions) chemically reduced the soil porosity by replacing soil multi-valent cations. Highly expanding clays, such as bentonite, when wetted, effectively reduced soil permeability. It was found that chemical sealing was effective for soils with a minimum clay content of 8 percent and a silt content of 10 percent. Effectiveness increased with clay and silt content. The most commonly used salts for chemical sealing have been sodium polyphosphates, sodium carbonate, and sodium chloride.

In the study mentioned above, the sodium tripolyphosphate was applied to silt loam at 0.46 lb/yd^2 at $303/ac (1974 prices, New Zealand). Sodium carbonate was applied to silt loam and sand loam at 0.70 lb/yd^2 at $162/ac. For soils with less than the above percentages, chemical treatment was not effective. Physical treatment with bentonite, for example, would have effectively sealed these soils. Bentonite has been found to swell eight to twenty times its original volume. The application for bentonite rate in the study was 4.6 lb/yd^2 at a cost of $502/ac. These methods of sealing were found to be less expensive than synthetic or earthen liners (see Figures 1-5 for infiltration rates).

Four different soil columns were placed at the bottom of an animal wastewater pond to study physical and chemical properties of soil and sealing of wastewater ponds (Chang et al., 1974). It was discovered that the initial sealing which occurred at the top 2 in. of the soil columns was caused by the trapping of suspended matter in the soil pores. This was followed by a secondary mechanism of microbial growth that completely sealed off the soil from water movement.

A similar study was performed in Arizona (Wilson et al., 1973). The double mechanism of physical and biological sealing was also found to occur. Seepage rate was measured during the first 3 months. Percolation from the lagoon was measured from 70 ft below the surface. The sealing of the lagoon was also induced by the use of an organic polymer united with bentonite clay. This additive could have been applied with

Table 6. Important physical properties of soils and their uses for pond linings (identifications based on unified soil classification system) (Day et al., 1970).

MAJOR DIVISIONS OF SOILS			TYPICAL NAMES OF SOIL GROUPS	GROUP SYMBOLS	SOIL PROPERTIES: PERMEABILITY	SOIL PROPERTIES: SHEARING STRENGTH	SOIL PROPERTIES: COMPACTED DENSITY	SUITABILITY FOR LINING: EROSION RESISTANCE	SUITABILITY FOR LINING: COMPACTED EARTH LININGS
COARSE-GRAINED SOILS More than half of material is larger than No 200 sieve size (The No. 200 sieve size is about the smallest particle visible to the naked eye)	GRAVELS More than half of coarse fraction is larger than No.4 sieve size (For visual classifications, the 1/4" size may be used as equivalent to the No.4 sieve size)	CLEAN GRAVELS (Little or no fines)	Well-graded gravels, gravel-sand mixtures, little or no fines	GW	14	16	15	2	—
			Poorly graded gravels, gravel-sand mixtures, little or no fines	GP	16	14	8	3	—
		GRAVELS WITH FINES (Appreciable amount of fines)	Silty gravels, poorly graded gravel-sand-silt mixtures	GM	12	10	12	5	6
			Clayey gravels, poorly graded gravel-sand-clay mixtures	GC	6	8	11	4	2
			Gravel with sand-clay binder	GW-GC	8	13	16	1	1
	SANDS More than half of coarse fraction is smaller than No.4 sieve size	CLEAN SANDS (Little or no fines)	Well-graded sands, gravelly sands, little or no fines	SW	13	15	13	8	—
			Poorly graded sands, gravelly sands, little or no fines	SP	15	11	7	9 coarse	—
		SANDS WITH FINES (Appreciable amount of fines)	Silty sands, poorly graded sand-silt mixtures	SM	11	9	10	10 coarse	7 Erosion Critical
			Clayey sands, poorly graded sand-clay mixtures	SC	5	7	9	7	4
			Sand with clay binder	SW-SC	7	12	14	6	3
FINE-GRAINED SOILS More than half of material is smaller than No. 200 sieve size	SILTS AND CLAYS Liquid limit less than 50		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	ML	10	5	5	—	8 Erosion Critical
			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	CL	3	6	6	11	5
			Organic silts and organic silt-clays of low plasticity	OL	4	2	3	—	9 Erosion Critical
	SILTS AND CLAYS Liquid limit greater than 50		Inorganic silt, micaceous or diatomaceous fine sandy or silty soils, elastic silts	MH	9	3	2	—	—
			Inorganic clays of high plasticity, fat clays	CH	1	4	4	12	10 Volume Change Critical
			Organic clays of medium to high plasticity	OH	2	1	1	—	—
HIGHLY ORGANIC SOILS			Peat and other highly organic soils	Pt	*			**	

* Numbers above indicate the order of increasing values for the physical property named
** Numbers above indicate relative suitability (1 = best)

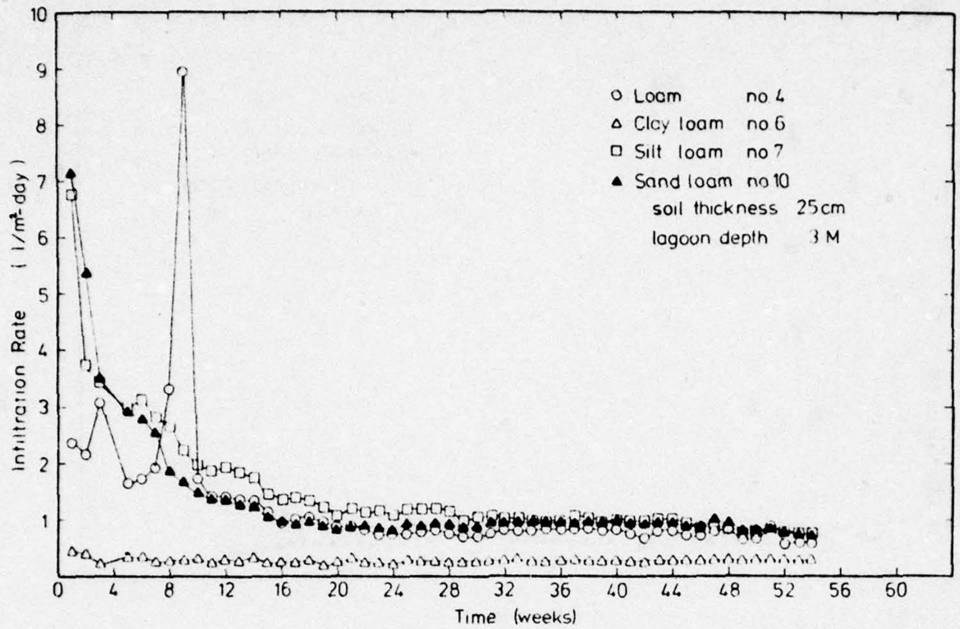


Figure 1. Infiltration rates--soil type effects (Hills, 1976). Courtesy of Journal Water Pollution Control Federation, Washington, D.C.

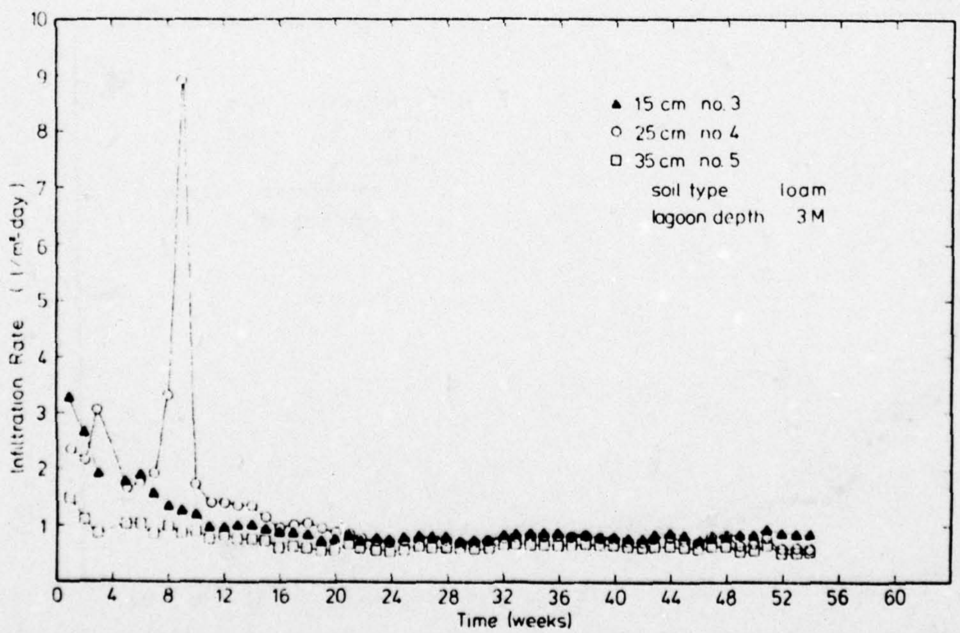


Figure 2. Infiltration rates--soil thickness effects (Hills, 1976). Courtesy of Journal Water Pollution Control Federation, Washington, D.C.

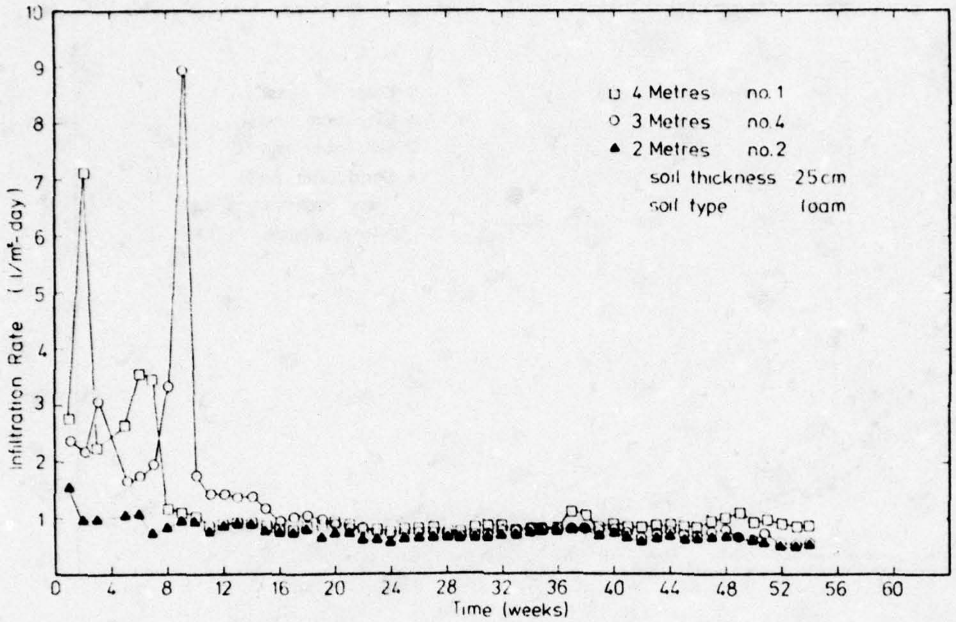


Figure 3. Infiltration rates--lagoon depth effects (Hills, 1976). Courtesy of Journal Water Pollution Control Federation, Washington, D.C.

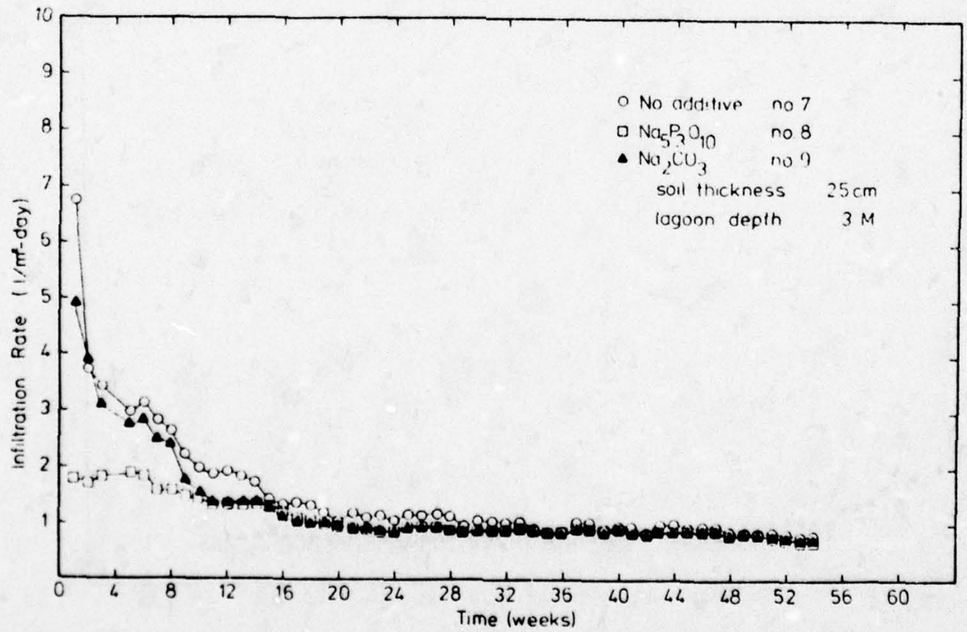


Figure 4. Infiltration rates--effects of additives in silt loam (Hills, 1976). Courtesy of Journal Water Pollution Control Federation, Washington, D.C.

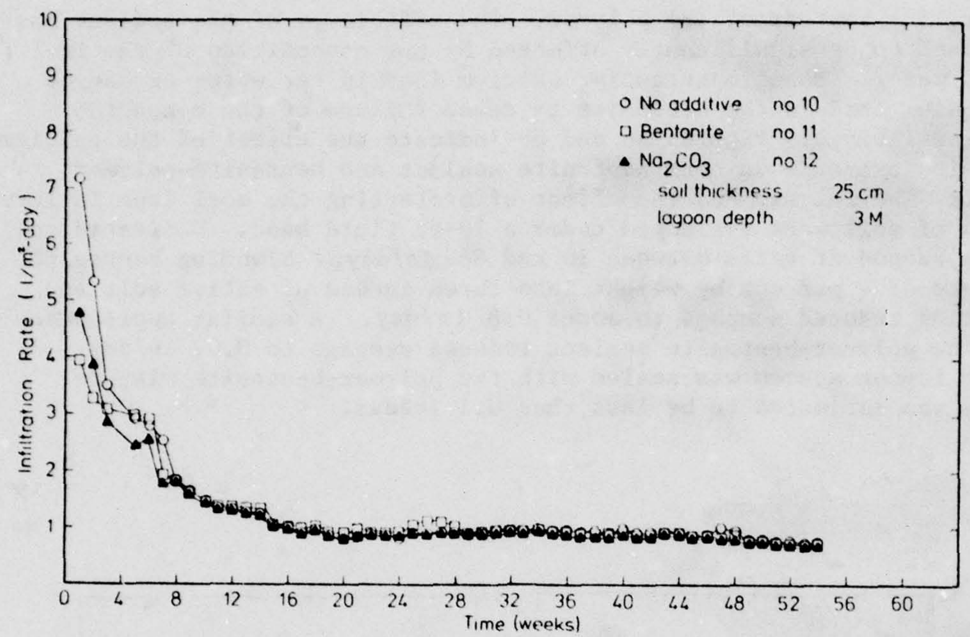


Figure 5. Infiltration rates--effects of additives in sand loam (Hills, 1976). Courtesy of Journal Water Pollution Control Federation, Washington, D. C.

the pond full or empty, although the treatment was more effective when the pond was empty.

An experiment was performed by Matthew and Harms (1969) in an effort to relate the sodium adsorption ratio (SAR) of the in situ soil to the sealing mechanism of wastewater stabilization ponds. The experiments were performed in South Dakota. No definite quantitative conclusions were formed. The general observation was made that the equilibrium permeability ratio decreases by a factor of 10 as SAR varies from 10 to 80. For 7 out of 10 soil samples, the following were concluded: (1) SAR did affect permeability of soils studied; (2) as the SAR increased, the probability that the pond would seal naturally also increased; and (3) soils with higher liquid limits would probably be less affected by the SAR.

Polymeric Sealants have been used to seal both filled and unfilled ponds (Rosene and Parks, 1973). Unfilled ponds have been sealed by admixing a blend of bentonite and the polymer directly into the soil lining. Filled ponds have been sealed by spraying the fluid surface with alternate slurries of the polymer and bentonite. It has been recommended that the spraying take place in three subsequent layers: (1)

polymer, (2) bentonite, (3) polymer. The efficiency of the sealant has been found to be significantly affected by the composition of the impounded water. Most importantly, calcium ions in the water exchanged with sodium ions in the bentonite to cause failure of the compacted bentonite linings. Figures 6a and 6b indicate the effect of the calcium-sodium ion exchange on both bentonite sealant and bentonite-polymer sealant. The polymer had the effect of protecting the seal from failure. Samples of soil were evaluated under a 10-ft fluid head. Untreated soil samples seeped at rates between 10 and 88 in/day. Blending bentonite at a rate of 4 percent by weight into three inches of native soil and compacting reduced seepage to about 0.8 in/day. A similar application using the polymer-bentonite sealant reduced seepage to 0.02 in/day. A 16-acre lagoon system was sealed with the polymer-bentonite mixture. Seepage was estimated to be less than 0.1 in/day.

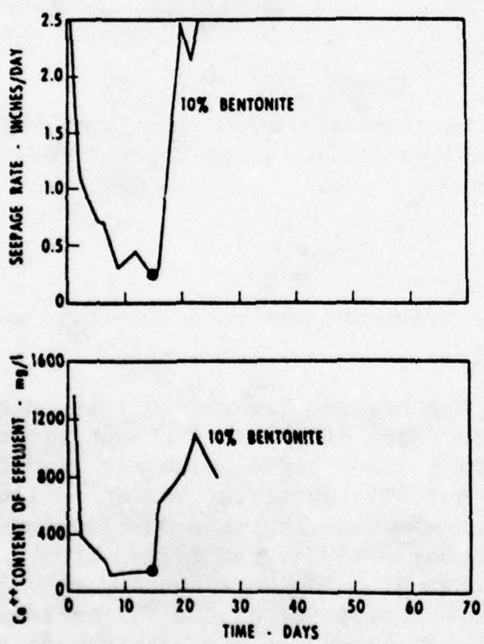


Figure 6a. Effect of calcium-sodium ion exchange on seepage rate of compacted bentonite sealant (Rosene and Parks, 1973). Courtesy of the Water Resources Bulletin, Minneapolis, Minnesota.

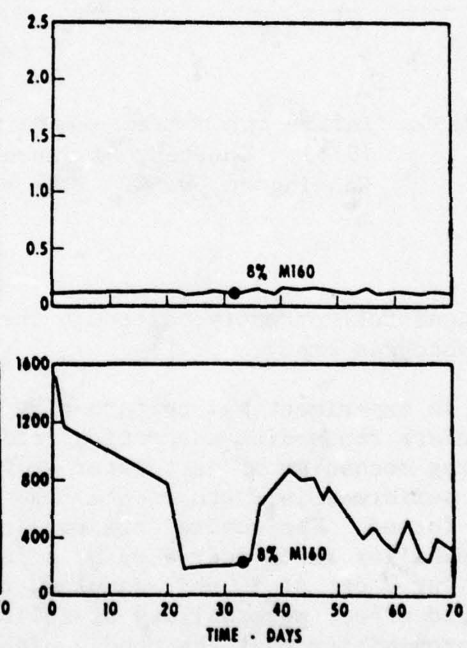


Figure 6b. Effect of calcium-sodium ion exchange on compacted bentonite-polymer sealant (Rosene and Parks, 1973). Courtesy of the Water Resources Bulletin, Minneapolis, Minnesota.

Natural sealing of lagoons has been found to occur from three mechanisms: (1) physical clogging of soil pores by settled solids, (2) chemical clogging of soil pores by ionic exchange, and (3) biological and organic clogging caused by microbial growth at the pond lining. The dominant mechanism of the three has been shown to depend on the composition of the wastewater being treated. Davis et al. (1973) found that for liquid dairy waste the biological clogging mechanism predominated. In a San Diego County study site located on sandy loam, the infiltration rate of a virgin pond was measured. A clean water infiltration rate for the pond was 48 in/day. After two weeks of manure water, infiltration averaged 2.3 in/day; after 4 months 0.2 in/day.

A study performed in southern California (Robinson, 1973) indicated similar results. After waste material was placed in the unlined pond in an alluvial silty soil, the seepage rate was reduced. The initial 4.4 in/day seepage rate dropped to 0.22 in/day after three months, and after six months to 0.12 in/day.

Stander et al. (1970) presented a summary of information (Table 7) on measured seepage rates in wastewater stabilization ponds. The results in Table 7 are similar to the values mentioned elsewhere in this report. Seepage is a function of so many variables it is impossible to anticipate or predict rates without extensive soils tests. The importance of controlling seepage to protect groundwater dictates that careful evaluations be conducted before construction of lagoons to determine the need for linings and the acceptable types.

Sanks et al. (1975) conducted a survey to determine the suitability of clay beds for the storage of industrial solid waste. It was concluded that industrial solid waste can be stored in selected geological locations through the use of a multiple passive barrier concept, proper site selection and pit preparation.

A rational design of clay pits requires a knowledge of the following: (1) the quantity and characteristics of the waste to be stored; (2) the location of groundwater and paths of percolation; (3) the sorptive and ion exchange properties of the clay, and (4) the permeability of the prepared clay liner and the natural clay beds.

Five Texas clays studied were found to be capable of providing a substantial barrier to the migration of pollutants. All of the clays were highly impermeable and the remolded clays had coefficients of permeability for distilled water ranging from 0.051 to 6.3×10^{-9} in/sec. Strong acid conditions increased the permeability of three remolded clays packed at low densities. Caustic solutions greatly reduced the flow rate, and the addition of phenol-like substances and heavy metals appeared to have little effect on the flow.

The design of an industrial solid waste disposal facility could best be conducted by selecting consultants with a specialty in geotechnics and a background in industrial waste management. Careful field

Table 7. Reported seepage rates from pond systems (Stander et al., 1970).[d]

Literature Source	Initial Rates: Initial Seepage Rate ins/day	Initial Seepage Rate gals/acre/d	Hydraulic Load gals/acre/d	Seepage Rate as % of Hydraulic Load	Settling-in Period	Eventual Rates: Eventual Seepage Rate ins/day	Eventual Seepage Rate gals/acre/d	Hydraulic Load gals/acre/d	Seepage Rate as % of Hydraulic Load	Geology of Pond Base	Place
California SWPCB (Nos. 15, 18)	8.8	199,000	316,000	63	9 months	0.35	7,940	±380,000	2.1	Desert soil (sandy soil)	Mojave, California
Neal and Hopkins[a] (1956)	5.5	127,850	141,970	90	1 year	0.61	13,810	47,323	29.2	Sand and gravel	Kearney, Nebraska
Voights (1955)[b]	-	-	-	-	Average over 5 years (1951-55)	0.34	7,660	9,160	84	Sandy soil	Filer City, Michigan
Shaw (1962)	6	136,000	54,000	Exceeded inflow rate	±1 year	0.3	6,800	50,000	13.6	Clay loam and shale	Pretoria
Windhoek mun. maturation ponds:[c]											
Nos. 5	0.16	3,500	776,000	0.45	Over period 14th-22nd June 1967 after all ponds in full operation	-	-	-	-	Mica and schist	Windhoek, S.W.A.
6	0.17	3,900	1,190,000	0.32		-	-	-	-	Mica and schist	
7	0.015	300	712,000	0.046		-	-	-	-	Mica	
8	0.06	1,400	715,000			-	-	-	-	Mica and schist	
9	0.23	5,300	455,000			-	-	-	-	Mica and schist with side wall seepage to river	

[a]Evaporation and rainfall effects were apparently not corrected for. Seepage losses were also influenced by a high water table at times.

[b]These lagoons were constructed in sandy soil with the express purpose of seeping away Paper Mill NSSC liquor.

[c]Ponds constructed for the express purpose of water reclamation.

[d]Courtesy of Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan.

exploration should be planned on the basis of the known geology of the area and detailed boring tests. The importance of field permeability tests was emphasized, and it was recommended that care be exercised in preparing the borings so that meaningful results would be obtained. Because little is known about the effects of various chemicals on the permeability of clay, it was recommended that laboratory tests be conducted on undisturbed cores to correlate the permeabilities for water with permeabilities for expected leachates. Because of the large percentage of shrinking and swelling in clays, the moisture must be carefully controlled during construction to obtain an impervious lining and to prevent cracking. Natural clays are frequently more impermeable than remolded clays, and therefore it was recommended that natural clays not be disturbed except in areas where cracks, aquifers, or other pathways for leakage make it necessary. The importance of laboratory evaluations and careful field studies by competent personnel were emphasized greatly in the report. It would appear that many of the difficulties encountered with clay linings in the past can be attributed to improper design and construction techniques.

The Minnesota Pollution Control Agency (Hannaman et al., 1978) initiated an intensive study to evaluate the effects of stabilization pond seepage from five municipal systems. The five communities were selected for study on the basis of geologic setting, age of the system, and past operating history of the wastewater stabilization pond. The selected ponds were representative of the major geomorphic regions in the state, and the age of the systems ranged from 3 to 17 years.

Estimates of seepage were calculated by two independent methods for each of the five pond systems. Water balances were calculated by taking the difference between the recorded inflows and outflows, and pond seepage was determined by conducting in-place field permeability tests of the bottom soils at each location. Good correlation was obtained with both techniques.

Field permeability tests indicated that the sealing ability of the sludge blanket was insignificant in locations where impermeable soils were used in the construction process. In the case of more permeable soils, it appeared that the sludge reduced the permeability of the bottom soils from a background level of 10^{-4} or 10^{-5} in/sec to the order of 10^{-6} in/sec. At all five systems evaluated, the stabilization pond was in contact with the local groundwater table. Local groundwater fluctuations had a significant impact on seepage rates. The reduced groundwater gradient resulted in a reduction of seepage losses at three of the sites. The contact with the groundwater possibly explains the reduction in seepage rates with time observed in many ponds. In the past this reduction in seepage rates has been attributed to a sludge buildup, but perhaps the increase in contact with groundwater accounts for this reduction. In an area underlain by permeable material where little groundwater mounding occurs, there is probably little influence on seepage rates. The buildup of sludge on the bottom of a pond appears to enhance the ability of the system to treat seepage water. Sludge accumulation apparently increases the cation exchange capacity of the bottom soils.

Groundwater samples obtained from monitoring wells did not show any appreciable increases in nitrogen, phosphorus, or fecal coliform over the background levels after 17 years of operation. The groundwater down gradient from the waste stabilization pond showed an increase in soluble salts as great as 20 times over background levels. Concentrations from 25 mg/l of chlorides to 527 mg/l were observed.

Emphasis was placed on the need to seal the primary pond to the extent that the water level is maintained at a level adequate to ensure that the natural biological processes occurring in a waste stabilization pond will not be inhibited by fluctuations. It was observed that proper water level maintenance in the primary pond eliminated nuisance conditions and the potential for enteric organisms to enter the groundwater flow system. The current recommended design seepage rate of 500 gal/ac/day was felt to be a good guide for the design of primary pond systems. The control of seepage from secondary ponds appeared to be of less concern than that observed for the primary ponds.

Reviews, General Evaluations, Costs, and Summary

The selection of the proper lining for a lagoon or holding pond remains site specific. Each site must be individually analyzed for specific characteristics. These characteristics include: (1) composition of wastewater, (2) physical and chemical soil characteristics, (3) local climate, (4) local lagoon seepage regulations, and (5) project cost limitations (Morrison et al., 1971).

Dallaire (1975) presented a series of case histories describing the application of various types of liners to industrial waste lagoons with emphasis on the synthetic liners. Applications of synthetic liners in storm water overflow holding ponds, sanitary landfill linings to retain leachate and salt solution retaining ponds were also discussed. Descriptions of the construction methods used to protect the liners were presented. The article also included a summary of the options normally available to engineers to obtain an impermeable lining in a lagoon or holding pond. Five options were discussed: (1) a clay blanket, (2) a lime-clay blanket, (3) a soil-cement blanket, (4) asphaltic concrete, and (5) a plastic or rubber impermeable liner. The advantages and disadvantages of each option were presented.

Haxo and White (1974) and Haxo and White (1976) have presented an evaluation of 12 liner materials exposed to landfill leachate. Six polymeric liner membranes (butyl rubber, chlorinated polyethylene, chlorosulfonated polyethylene, ethylene propylene rubber, polyethylene, and polyvinyl chloride), four admix materials (hydraulic asphalt concrete, paving asphalt concrete, soil asphalt, soil cement) and two asphaltic membranes (a blown asphalt-canal lining asphalt, and emulsified asphalt on fabric) were prepared according to recommended procedures and

exposed to the leachate. After a one-year exposure of the liners to the leachate, the admix liners containing asphalt maintained their impermeability to leachate; however, a drastic decrease in comprehensive strength occurred. The asphalt became softer, and this was attributed to possible absorption of organic components from the leachate.

During the one year of monitoring in the above study, only three cells failed and two of these liners, soil asphalt and paving asphalt concrete, leaked, whereas the leakage in the third was caused by failure of the sealing compound around the periphery of the specimen. Soil cement lost some of its compressive strength, and its permeability decreased to some degree. Inhomogeneities in the admix materials were thought to contribute to the failure of the paving asphalt and soil asphalt liners because of the 2-4-inch-thick liners used in the study. In practice a much thicker application rate would be recommended. There is no indication of disintegration or dissolving of the asphaltic membranes during the one year test period, although a slight swelling occurred. All of the polymeric liner materials withstood a one year exposure to the leachate, but the chlorinated polyethylene and Hypalon (chlorosulfonated polyethylene) swelled appreciably. The swelling softened the liners, but a reduction in tensile, tear, or puncture resistance was not observed. Preliminary tests of the polymeric liner materials indicated some increase in permeability which was attributed to swelling. Reductions in the strengths of the seams of polyvinyl chloride, Hypalon, and chlorinated polyethylene liners were observed with the polyethylene retaining its strength best.

The leachate to which the liners were exposed had a COD of 40,000-50,000 mg/l and approximately 20,000 mg/l of organic acids. The simulated landfills were effective and produced anaerobic conditions which yielded satisfactory leachates and a meaningful test of the lining materials. All of the construction materials, except the epoxy resins used to seal the liners in the base of the test facility showed no significant deterioration. The resin selected was not designed for chemical resistance, and for the continuation studies a more resistant material has been developed.

Haxo et al. (1977) have presented the results of an interim study describing the effects of liner materials exposed to hazardous and toxic sludges. The experimental facility is constructed to simulate actual operating conditions, and in addition to the exposure of sludges at depths, plywood troughs with sloping sides are constructed for exposing liners under conditions which simulate those encountered around the edges of wastewater stabilization ponds.

The five types of admix materials exposed during the testing with their respective thicknesses are listed below:

Asphalt emulsion on nonwoven fabric (0.3 in.)
Compacted native fine-grain soil (12 in.)
Hydraulic asphalt concrete (2.5 in.)
Modified bentonite and sand (5 in.)
Soil cement with and without surface seal (4 in.)

Eight types of polymeric membrane liners have been exposed to toxic substances and the types of materials and their thicknesses are listed below:

Butyl rubber, fabric reinforced (34 mils)
Chlorinated polyethylene (32 mils)
Chlorosulfonated polyethylene, fabric reinforced (34 mils)
Elasticized polyolefin (20 mils)
Ethylene propylene rubber (50 mils)
Neoprene, fabric reinforced (32 mils)
Polyester, elastomer, experimental (8 mils)
Polyvinyl chloride (30 mils)

All of the polymeric membrane liners were mounted with lap seams prepared by the suppliers or by the contractor in accordance with recommended procedures.

The six classes of hazardous waste selected for the study were: strong acid, strong base, waste of saturated and unsaturated oils, lead waste from gasoline tanks, oil refinery tank bottom waste (aromatic oil), and pesticide waste. Preliminary exposure tests were conducted on the various kinds of materials to select combinations for long term exposure. Most of the membrane liners and all of the asphaltic materials either swelled or dissolved in the aromatic hydrocarbons. Combinations of waste and liners exhibiting these characteristics were eliminated. The clay liners were incapable of holding acidic and caustic wastes for extended periods of time, and these combinations were also dropped from the long-term exposure test.

The results obtained during the first year of limited bench scale testing of liner materials exposed to various wastes resulted in the following conclusions:

1. Liners should be carefully selected for specific wastes.
2. Preliminary exposure tests should be conducted on liner materials before a specific liner is selected.
3. Asphalt based liners are incapable of containing oily wastes.
4. With the exception of crystalline polymeric membranes, oily wastes, and particularly those containing aromatic components, may pose special problems. Non-crystalline materials such as rubber and PVC swell in oily wastes and swelling can be particularly damaging to seams using cement compounds.
5. Bentonite liners, polymer modified bentonite and many soils are probably unsatisfactory materials to be used for the confinement of strong acids and bases and concentrated brines.
6. Wastes containing both aqueous and oily phases may pose special problems because of the need of the liner to resist simultaneously two fluids which are inherently different in their compatibility with materials.

This study is continuing and being expanded and the detailed analyses of the wastes used to expose the liners are being conducted.

Cost comparisons of various liners (Tables 8 and 9) indicate that natural and chemical sealants are the most economical sealers. Unfortunately, natural and chemical sealers are dependent on local soil conditions for seal efficiency and never form a complete seal. Asphalt type and synthetic liners compete competitively on a cost basis, but have different practical applications. Synthetic liners are most practical for zero or minimum seepage regulations, for industrial waste that

Table 8. Cost of installed liner (Clark and Moyer, 1974).

Liner	$/sq ft
Bentonite	
2 lb/sq ft	0.14
Chemical	
Sodium Carbonate	0.02
Sodium Silicate	0.02
Sodium Pyrophosphate	0.03
Zeogel	0.03
Coherex	0.03
Asphalt	
Asphalt Membrane	0.14
Asphalt Concrete	0.20
Rubber[a]	
Butyl	
1/16 in.	0.42
3/16 in.	0.36
1/32 in.	0.30
EPDM	
1/16 in.	0.41
3/64 in.	0.35
1/32 in.	0.29
Synthetic Membrane	
PVC	
10 mils	0.13
20 mils	0.18
30 mils	0.22
Chlorinated Polyethylene (CPE)	
20 mils	0.26
30 mils	0.34
Hypalon	
20 mils	0.26
30 mils	0.34
Fiber glas	
1/8 in.	0.55

[a]Nylon reinforced rubber costs an additional $0.10/sq ft.

Table 9. Comparison of various installed liner costs, 1962 cost figures (Stoltenberg, 1970).[a]

Liner Type	Cost ($\$/ft^2$)
Prefabricated Plastic	0.03 - 0.10
Composite PVC and Asphalt	0.09
Butyl Rubber Membranes	0.40
Bentonite Clay	0.60
Prefabricated Asphalt	0.11
Spray-type Cutback / Emulsion Asphalt	0.02
Spray-type Catalytically-blown Asphalt	0.08
Asphalt/Concrete (Hot Mix)	0.30
Soil Cement	> 0.30

[a]Courtesy of Public Works, Ridgewood, New Jersey.

might degrade concrete or earthen liners, and for extremes in climatic conditions.

Kays (1977) has written a book describing the technology of linings for seepage control in reservoirs, lakes, ponds, canals, and related hydraulic facilities. Emphasis is given to earthen reservoirs, but other forms of containment such as concrete and steel tanks are also discussed. The lining classifications discussed in the book are summarized in Table 10. The book is an excellent analysis of the technology of linings and is recommended as a guide for all construction and engineering firms.

A brief history on the application of linings is presented describing the types of reservoirs frequently encountered. Flexible, rigid, and miscellaneous lining systems are discussed individually and the basic problems associated with the selection of an elastomeric lining material are presented.

A good analysis of the failure mechanisms involved in various types of linings is also discussed. A chapter is devoted to pollution control linings and the various types of waste products retained. Holding ponds, harvesting ponds, groundwater contamination, airborne and thermal pollution are discussed briefly. Detailed recommended design procedures are also presented along with instructions for operation and maintenance with the various types of linings.

The primary emphasis of the book is on plastic and elastomeric membranes. The major advantages of zero permeability, good economics, and large sheet capability along with their basic properties, testing,

Table 10. Lining classifications (Kays, 1977).[a]

Flexible	Rigid	Miscellaneous
Plastics	Gunite	Bentonite clays
Elastomers	Concrete	Chemical treatments
Asphalt panels	Steel	Waterborne treatments
Compacted soils	Asphalt concrete	Combinations
	Soil cement	

Impervious	Semiimpervious
Plastics	Compacted soils
Elastomers	Gunite
Asphalt panels	Concrete
Steel	Asphalt concrete
	Soil cement
	Bentonite clays
	Chemical treatments
	Waterborne treatments

Continuous	Noncontinuous
Plastics	Compacted soils
Elastomers	Gunite
Asphalt panels	Concrete
Steel	Asphalt concrete
	Soil cement
	Bentonite clays
	Chemical treatment
	Waterborne treatments

[a]Courtesy of John Wiley & Sons, Inc., New York, N.Y.

fabrication cost and installation techniques are described in detail. The discussion of non-continuous lining systems such as concrete, gunite, asphalt concrete, compacted earth, bentonite, and chemical treatments are also adequately discussed.

Figure 7 is taken from Kays' (1977) work and shows comparative construction cost ranges for concrete and steel tanks and cut and fill reservoirs. Figure 8 shows a cost comparison for the various types of liners used in the United States. Kays (1977) presented a classification of the principal failure mechanisms observed in cut-and-fill reservoirs (Table 11). The list is extensive and case histories involving all of the categories are available; however, the most frequently observed failure mechanisms were the lack of integrity in the lining support

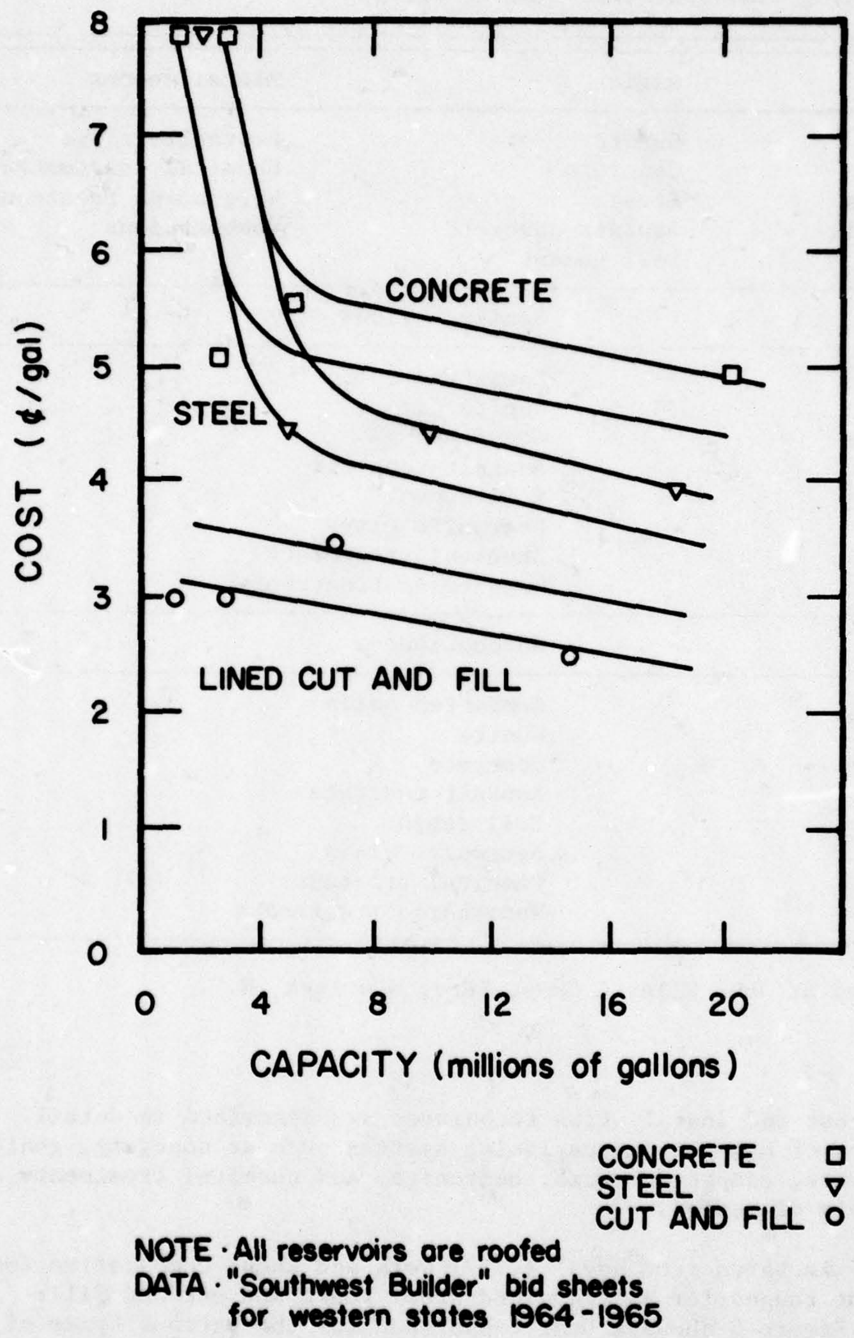


Figure 7. Comparative construction cost ranges for concrete and steel tanks and cut-and-fill reservoirs. Legend: concrete, □; steel, ▽; cut-and-fill, ○. All reservoirs are roofed (data from "Southwest Builder" Bid Sheets for Western States, 1964-1965) (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.

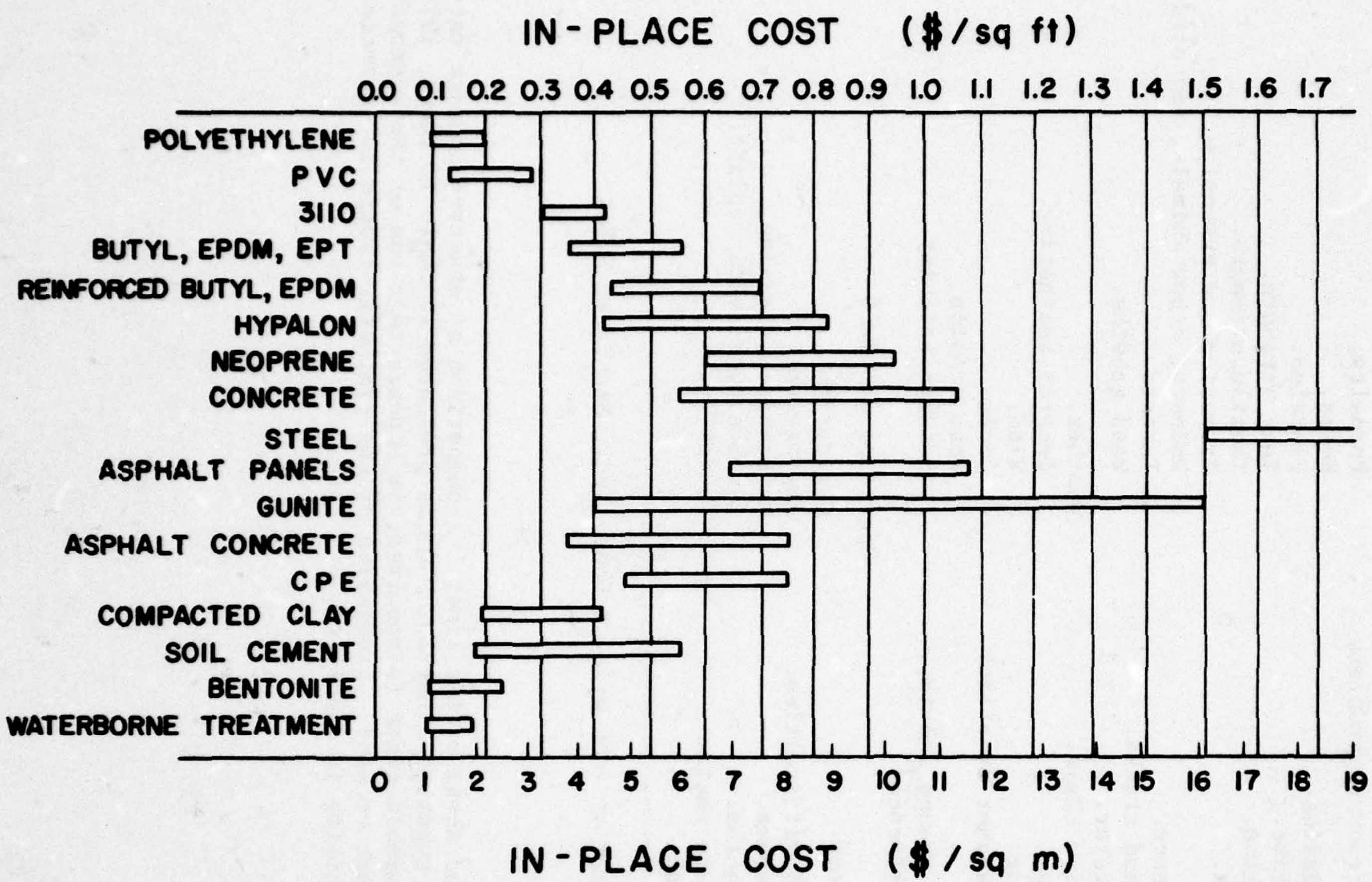


Figure 8. Cost comparison for linings in the United States (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.

Table 11. Classification of the principal failure mechanisms for cut-and-fill reservoirs (Kays, 1977).[a]

Supporting structure problems

- The underdrains.
- The substrate.
    - Compaction.
    - Texture.
    - Voids.
    - Subsidence.
    - Holes and cracks.
    - Groundwater.
    - Expansive clays.
    - Gassing.
    - Sluffing.
    - Slope anchor stability.
    - Mud.
    - Frozen ground and ice.
- The appurtenances.

Lining problems

- Mechanical difficulties.
    - Field seams.
    - Fish mouths.
    - Structure seals.
    - Bridging.
    - Porosity.
    - Holes.
    - Pinholes.
    - Tear strength.
    - Tensile strength.
    - Extrusion and extension.
    - Rodents, other animals, and birds.
    - Insects.
    - Weed growths.
- Weather.
    - General weathering.
    - Wind.
    - Ozone.
    - Wave erosion.
    - Seismic activity.

Operating problems

- Cavitation.
- Impingement.
- Maintenance cleaning.
- Reverse hydrostatic uplift.
- Vandalism.

[a]Courtesy of John Wiley & Sons, Inc., New York, N.Y.

structure and abuse of the liner. A comparison of observed seepage rates for various types of liner materials is presented in Table 12 (Kays, 1977). If an impermeable liner is required, it appears that one of the synthetic materials must be used. Protection of the synthetic liners is essential if impermeability is specified.

Table 12. Seepage rate comparisons[a] (Kays, 1977).[b]

Material	Thickness (in.)	Minimum Expected Seepage Rate at 20 ft of Water Depth After 1 yr of Service (in./day)
Open sand and gravel		96
Loose earth		48
Loose earth plus chemical treatment*		12
Loose earth plus bentonite*		10
Earth in cut		12
Soil cement (continuously wetted)	4	4
Gunite	1.5	3
Asphalt concrete	4	1.5
Unreinforced concrete	4	1.5
Compacted earth	36	0.3
Exposed prefabricated asphalt panels	0.5	0.03
Exposed synthetic membranes	0.045	0.001

[a]The data are based on actual installation experience. The chemical and bentonite (*) treatments depend on pretreatment seepage rates, and in the table loose earth values are assumed.

[b]Courtesy of John Wiley & Sons, Inc., New York, N.Y.

STATE DESIGN STANDARDS

Each of the 50 states was contacted by mail with a follow-up by telephone where necessary to obtain information about the requirements for liners in wastewater stabilization lagoons and allowable seepage rates from lagoons. The results of the survey are summarized in Table 13. Requirements vary from state to state, but in general all specify as a minimum that the beneficial uses of the groundwater beneath a wastewater stabilization lagoon be protected. Recommended methods for protection of the groundwater range from natural sealing to impervious linings and stringent leakage allowances.

Written standards varied from a one short paragraph statement leaving the selection of liners and establishment of seepage rates to the discretion of the regulatory agency to detailed written descriptions illustrated with drawings showing the acceptable methods of design and construction. Washington and Minnesota standards were the most detailed of all and both sets of standards are presented as Appendixes A and B.

None of the various types of liners were specifically excluded from application in any of the 50 states; however, the strict allowable seepage rates imposed by certain states would make it difficult to employ many of the soil stabilization techniques discussed in other sections of this report. The most common method of specifying allowable seepage rates was to specify protection of the groundwaters without establishing a minimum seepage rate.

Several states expressed concern about groundwater pollution from lagoons containing industrial wastes with toxic substances such as heavy metals and exotic organic compounds. Many of these states indicated they are presently modifying standards or are considering revisions. The trend is definitely toward more stringent standards.

Experiences with various materials and application techniques were also cited as reasons to improve the regulations. Opinions as to the best lining material varied from state to state, and the favored material varied with the availability of natural materials for linings and the local soil conditions. The need for competent professional services was emphasized by most states.

It appears reasonable to assume that standards will become more stringent and that more detailed guidelines will be developed by many of the states. Heavily industrialized states can be expected to require essentially impervious linings for most industrial applications. It is likely that military installations will be expected to use impervious linings in applications where a mixture of domestic and industrial wastes is discharged to a stabilization lagoon.

Table 13. Summary of state requirements for liners and seepage rates in wastewater stabilization lagoons.

State	Lining Requirement	Seepage Limitations	Remarks
Alabama	Required lining determined by geological/hydrological/evaluation.	None specified. General intent is to provide an impervious structure.	One to two feet of compacted clay is usual liner. Bentonite has been used, but generally prohibitively expensive. Degradation of synthetic liners noted particularly in oil fields.
Alaska	Lining requirements determined on a case-by-case evaluation. Location in an alluvial plain or other areas of high permeability would require lining.	No specified allowable seepage rate. Decided on a case-by-case basis.	Protection of groundwaters is main objective of standards.
Arkansas	Need evaluated on a case-by-case basis. No standards developed for liners.	No specified allowable seepage rate. Protection of groundwater major criterion.	Lagoons and oxidation ditches are not allowed in areas with limestone strata.
Arizona	Required when wastewater contains toxic substances and there is a possibility of groundwater pollution. Completely impermeable lining required. Lagoons with domestic wastewater may be lined with clay. Unlined percolation ponds allowed where there is no danger of groundwater pollution.	Completely impermeable, no seepage when toxic substances in lagoon. Lining not required with domestic wastewater if percolation rate is greater than 60 minutes per inch.	Unwritten policy. Experience with 10 mil plastic liner was not satisfactory.
California	Need for liners evaluated on a case-by-case basis. Protection of groundwater is required.	No specified allowable seepage rate. Decided on a case-by-case basis.	Merits of various products evaluated at each site.
Colorado	Liner of same type required to prevent seepage into groundwater. All types of liners evaluated on individual merit.	No specified allowable seepage rate. Decided on a case-by-case basis.	
Connecticut	Need evaluated on a case-by-case basis. Types of liners evaluated on merits of materials.	No specified allowable seepage rate. Decided on a case-by-case basis.	Detailed analysis of local conditions and discharge site.

Table 13. Continued.

State	Lining Requirement	Seepage Limitations	Remarks
Delaware	Unlined lagoons not permitted where seepage could occur. All wastewater lagoons must have a plastic liner or be sealed with chemicals and/or clay materials.	Seepage not allowed.	
Florida	No restrictions on type of lining material. Wastewaters containing toxic substances require impermeable lining.	Related to type of wastewater, and quality and use of groundwater. Holding ponds for treated domestic wastewaters can have a seepage rate of 0.25 inch per day, but if local conditions indicate that a higher rate will not cause damage, this can be approved. If there are water supply wells within 1,000 feet of the holding pond, the pond shall be sealed to limit leakage to maximum rate of 0.1 inch per day.	Lack of suitable leakage detection system poses serious monitoring and enforcement problems.
Georgia	Need for liners evaluated on case-by-case basis. No restrictions in type of lining material.	No specified allowable seepage rate.	Have encountered problems and anticipate developing standards.
Hawaii	Protection of groundwater required. No restrictions on type of lining material.	No specified allowable seepage rate.	Most common types are concrete and butyl rubber.
Idaho	Protection of groundwater required. No restrictions on type of lining material.	Maximum allowable seepage rate is 1/4 inch per day.	Design specifications require best possible results with selected material.
Illinois	Prevention of pollution of groundwaters specified. No restrictions on type of lining material.	No specified allowable seepage rate.	

Table 13. Continued.

State	Lining Requirement	Seepage Limitations	Remarks
Indiana	Lining required to meet seepage limitations. Seals consisting of soils, bentonite, or synthetic liners allowed provided they meet permeability, durability, integrity and cost-effectiveness tests.	Equilization basins should have relatively tight bottoms with an initial percolation rate not exceeding 1/8 inch per day.	Consideration being given to establishing a fixed seepage rate such as a value of 500 gallons per day per acre. Local engineers feel that a rate of 500 gal/day-acre would exclude the use of clay type soils and bentonite, and synthetic or asphalt lining would be necessary.
Iowa	Liners evaluated on individual basis. Lagoons treating wastewater from animal feeding facilities do not require a lining.	Maximum allowable seepage rate shall be 1/8 inch per day. Method used to measure seepage rate must be specified in project specifications.	No problems encountered when facility does not extend into groundwater table and a bentonite clay lining is properly applied during construction. Bentonite selected over other materials because of cost advantage.
Kansas	Liners required to maintain water level and protect groundwater. All methods of sealing or lining are considered on individual merits.	No specified maximum allowable seepage rate. Impermeable bottom specified.	Areas with soils unable to retain water, removal of the bottom soil to a depth 1½ ft below finished grade and replacement with clay compacted to a maximum density at 1½% moisture as measured by standard Proctor Test.
Kentucky	No specific requirements regarding liners. Lagoon must hold water to a proper level to prevent a nuisance. Protection of groundwater also required.	No specified allowable seepage rate.	Need evaluated on a case-by-case basis.
Louisiana	No specific requirements regarding liners. Each lagoon proposal reviewed on its individual merits.	No specified allowable seepage rate.	Where soil porosities necessitate seepage control, clay blankets approximately two feet deep were used.
Maine	No official design criteria for lagoon liners.	The soil formation or structure of the bottom shall be sufficiently tight to preclude pollution due to seepage.	In most areas, soil conditions are such that liners are unnecessary.

Table 13. Continued.

State	Lining Requirements	Seepage Limitations	Remarks
Maryland	Lagoon bottom and the inner slope of the embankment shall be lined with impervious material such as clay, bentonite, or other sealing materials to preclude pollution by seepage. The lining shall extend from the bottom of the lagoon to at least 1 foot above the highest water level.	No specified allowable seepage rate.	Should adequate boring data be presented to substantiate the soil imperviability at the proposed lagoon site, lining with impervious material will not be required.
Massachusetts	No specific regulations or guidelines for liners. Approved on a case-by-case basis.	No specified allowable seepage rate.	Some industries have installed plastic liners. Specifications call for water tightness, anchorage tests, and typical operation tests for a full day to check for rips, tears and bond integrity.
Michigan	Linings required to prevent contamination of groundwater. Lagoon seals are always necessary.	No policy statement, but 1/16 to 1/8 inch per day has been the generally accepted maximum rate of seepage with 1-2 feet of water in the lagoon.	Where adequate sealing is not assured with clay soils, synthetic liners have been used. If suitable clay soils are available, a 1-1½ foot thick clay layer compacted in 3 or 4 lifts provides an adequate seal. Two foot thick layers of clay are compacted on the side slopes to prevent further leakage. Design of synthetic liners should include a means of relieving gases which may build up beneath the synthetic lining and cause failure. Linings should be placed on a 6 inch layer of sand and covered with 12 inches of loamy soil.
Minnesota	Linings required. Soils, bentonite, or synthetic liners may be considered provided the permeability, durability, integrity, and cost-effectiveness of the proposed material can be satisfactorily demonstrated for the anticipated conditions.	No specified allowable seepage rate. Detailed specifications for soil seals, bentonite, and synthetic liners are provided.	See appendices for details of standards.

Table 13. Continued.

State	Lining Requirements	Seepage Limitations	Remarks
Mississippi	Need for linings determined on a case-by-case basis. All types of liners acceptable. Decisions based on soil boring and investigations.	No specified allowable seepage rate. Protection of groundwater is criterion.	Many areas of state have highly impermeable clay soils which serve as effective liners.
Missouri	Lining required to meet allowable seepage rate.	Allowable seepage rate is 0.25 inch per day.	Anticipated that seepage rate will be changed to 500 gallons per acre per day. Soil material used most frequently to control seepage. Industrial lagoons are main users of synthetic liners.
Montana	Lining required to meet allowable seepage rate.	Initial allowable seepage rate is 1/4 inch per day.	Synthetic liners used only at industrial sites. Petroleum refineries using asphalt impregnated liners experienced dissolution of the asphalt at the water line by wastewater. Gunite above and below the water line solved the problem.
Nebraska	Sealing with a clay blanket, bentonite, or other material may be needed to control seepage rate.	Allowable seepage rate is: Design: 1/8 inch per day Construction: 1/4 inch per day	Most experience has been with bentonite. Found to be a good lining material when properly applied. Soil compaction also allowed to limit seepage. Most municipal and industrial lagoons use bentonite as a sealer, with an occasional plastic or rubber lining used in industrial situations.
Nevada	No specific requirements regarding liners. Each lagoon proposal reviewed on individual merits.	No specific allowable seepage rate. Allowable seepage rate established on a case-by-case basis.	Only a few facilities with lined lagoons.
New Hampshire	Linings not required except where excessive percolation is anticipated. Sealing of the bottom with clay blanket, bentonite, or other sealing material recommended when excessive seepage expected. Excessive seepage described as inability to maintain adequate water level in lagoons.	No specified allowable seepage rate. Only maintenance of adequate water level specified.	Only one clay-sealed lagoon consuructed in state. No reported pollution problems from seepage.

Table 13. Continued.

State	Lining Requirements	Seepage Limitations	Remarks
New Jersey	Linings required. Materials evaluated on individual merits.	No specified allowable seepage rate. Impermeable liner required.	Monitoring wells required in cases involving toxic substances or sensitive areas.
New Mexico	Lining required to control water quality. All types of lining materials considered.	No specified allowable seepage. Seepage is related to water quality and must not degrade groundwater or surface water.	Only bad experience has been with asphalt linings which split between the joints. Sidewalls of lagoons normally lined with gunite or concrete to control weeds and erosion of the dikes.
New York	Linings required to avoid excess liquid loss. All materials considered on their merits.	No specified allowable seepage rate. Protection of groundwater and maintenance of adequate water level specified.	Sealing with clay or bentonite and plastic or rubber materials receives equal consideration.
North Carolina	Lagoon linings required when water holding characteristics of the soil are unsatisfactory, when there is not satisfactory separation between lagoon bottom and groundwater table, when toxic wastes must be contained, and when embankments must be protected from wave action.	No specified allowable seepage rate.	Liner material must be compatible with the character of the waste. Lowest elevation of lagoon should not be within four feet of water table or bedrock. Monitoring facilities for groundwater required at lagoon site. Several failures of flexible liners installed in mechanical aeration basins have occurred. Reasons unknown.
North Dakota	Liner required to reduce seepage to acceptable limits. Clay locally available and most often used. Option given to cities and industry to use either clay or manmade liners.	Allowable seepage rate is 1/8 inch per day. Consideration being given to reducing this rate to 1/16 inch per day.	Good success reported with clay materials.
Ohio	No specific liner recommended, but protection of groundwater required.	No specified allowable seepage rate.	"Recommended Standards for Sewage Works" published by the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers are followed.

Table 13. Continued.

State	Lining Requirements	Seepage Limitations	Remarks
Oklahoma	Requirements specify that lagoons be essentially water-tight. Interpreted to be met when lagoon is constructed in a clay soil or lined with six inches of compacted clay.	No specified allowable seepage rate.	Abundance of clay in state precludes use of manmade materials.
Oregon	Linings required to meet seepage rates. Types of linings used include: soil materials, bentonite, hot mix asphalt, shot concrete, thin cast in place concrete, sprayed asphalt coating & PVC liners.	Lagoons are to be sealed to a net leakage rate of 1/4 inch per day.	Sheet liners (manmade materials) have performed poorly due to formation of gases beneath the membrane causing flotation of the lining. Some liners have been lifted by mechanical aerators.
Pennsylvania	Requires that lagoons be impermeable to safeguard the quality of groundwater. Seals of soil, bentonite, or synthetic liners may be suitable.	Seepage rate should be as low as practically possible and the coefficient of permeability in centimeters per second shall not exceed 1×10^{-7}	Flexible membrane linings shall have a minimum thickness of 20 mils.
Rhode Island	No specific requirements. Reviewed on a case-by-case basis.	No specified allowable seepage rate.	
South Carolina	No specific requirements. Lagoon sites must be monitored for changes in shallow groundwater quality.	No specified allowable seepage rate.	Experience shows that use of bentonite to control seepage is satisfactory when incorporated into the lagoon bottom during construction or after draining. When used as an additive or distributed over the surface, clay tends to stay suspended and does not seal bottom.
South Dakota	Linings required to meet seepage rates. All materials considered but only clay or bentonite has been installed.	Allowable seepage rate is 1/16 inch per day.	Chemical pollution possibility may require special consideration.
Tennessee	Water tight conditions required. Frequent test holes required to determine need for sealing.	No specified allowable seepage rate.	Investigation must be made to evaluate water-holding capability of the soil.

Table 13. Continued.

State	Lining Requirements	Seepage Limitations	Remarks
Texas	Linings required in areas with shallow usable groundwater.	Allowable seepage rate is equal to or less than 10^{-7} cm per second.	All earthen structures proposed for use in domestic wastewater treatment or storage shall be constructed so as to prevent percolation of the wastes which may contaminate the underground waters of the state.
Utah	Sealing required when allowable seepage rate is exceeded. Clay, bentonite, asphaltic coatings, or other sealing materials are acceptable.	Allowable seepage rate is 1/4 inch per day.	In areas where groundwater is a source of water supply sealing of ponds will be required.
Vermont	Liners required. Three basic types acceptable: 20 mil PVC, clay, and bentonite. Each project evaluated on an individual basis.	A material with a permeability of 1×10^{-7} cm per second is required.	Clay and PVC liners must be placed on the entire wetted perimeter of all lagoons. Wave action protection also required. PVC liner constructed with 9-12 inches of sand cushion both below and on top of the liner. Clay liners are 9-12 inches thick.
Virginia	Sealing or lining should be considered where excessive seepage is anticipated. Groundwater must be protected from pollution.	No specified allowable seepage rate.	
Washington	Liners required if native soils will not ensure seepage control. Soil, bentonite, or synthetic liners are acceptable.	Seepage rate shall not exceed 1/4 inch per day.	Currently developing standards listed in other columns. See appendix for recommended standards.
West Virginia	Linings required to protect groundwater. Only clay used because of availability of high quality clay. Standards established for clay but no other materials. Other materials reviewed on a job-by-job basis.	No specified allowable seepage rate.	Satisfactory sealing obtained with clay.

Table 13. Continued.

State	Lining Requirements	Seepage Limitations	Remarks
Wisconsin	Linings required to control water depth if seepage rate is excessive. Bentonite used most frequently to seal lagoons.	No specified allowable seepage rate.	Synthetic liners not used. Only one approved on experimental basis. Not yet installed.
Wyoming	Lining requirements determined on a case-by-case basis. Water depth in lagoon must be controlled.	No specified allowable seepage rate.	Clay blanket, bentonite, PVC or other type synthetic liners are acceptable for controlling seepage.

DESIGN AND CONSTRUCTION PRACTICE

The presentation of recommended design and construction procedures is divided into two categories: 1) bentonite, asphalt and soil cement liners, and 2) thin membrane liners. This division was selected because of the major differences between the application techniques. There is some similarity between the application of asphalt panels and the elastomer liners and of necessity there will be some repetition in these two major subdivisions. A partial listing of the trade names and sources of common lining materials is presented in Appendix C.

Regardless of the type of material selected as a liner there are many common design, specificiation and construction practices. A summary of the common effective design practices in cut-and-fill reservoirs is given in Table 14. Most of these practices are common sense items and would appear to not require mentioning. Unfortunately, experience has shown these items to be the most commonly ignored practices. Details of the design practices in Table 14 are presented in the following sections.

A lining material must be selected with the type of waste to be contained in mind. Kays (1977) has developed a lining selection guide chart (Table 15) for various types of wastes and the common types of lining materials. The chart should be used only as a guide, and before selecting one of the materials, a careful evaluation of the waste and the proposed liner must be conducted.

Bentonite, Asphalt and Soil Cement

The application of bentonite, asphalt and soil cement as lining materials for lagoons and reservoirs has a long history (Kays, 1977). The following summary includes consideration of the method of using the materials, resultant costs and evaluations of durability and effectiveness in limiting seepage. The cost analysis is necessarily somewhat arbitrary, since this cost depends primarily on the availability of the materials. Examples of state standards developed or being developed to control the application of these types of materials are presented in Appendixes A and B.

Types of Linings

Bentonite. Bentonite is a sodium type montmorillonite clay, and exhibits a high degree of swelling, imperviousness and low stability in

Table 14. Summary of effective design practice for placing lining in cut and fill reservoirs.

1. Lining must be placed in a stable structure.
2. Facility design and inspection should be the responsibility of professionals with backgrounds in liner applications and experienced in geotechnical engineering.
3. A continuous underdrain to operate at atmospheric pressure is recommended.
4. A leakage tolerance should be included in the specifications. The East Bay Water Company of Oakland, California, developed the following formula for leakage tolerance which has been modified by inserting more stringent factors in the denominator, i.e. 100, 200, etc.

$$Q = \frac{A\sqrt{H}}{80}$$

   where,

   Q = maximum permissible leakage tolerance, gallons/minute
   A = lining area, 1000 ft^2
   H = maximum water depth
   $Q \geqq 1.0$

5. Continuous, thin, impermeable type linings should be placed on a smooth surface of concrete, earth, Gunite, or asphalt concrete.
6. Except for asphalt panels all field joints should be made perpendicular to the toe of the slope. Joints of Hypalon formulations and 3110 materials can run in any direction, but generally joints run perpendicular to the toe of the slope.
7. Formal or informal anchors may be used at the top of the slope. See details in Figures 9-13.
8. Inlet and outlet structures must be sealed properly. See details in Figures 14-18.
9. All lining punctures and cracks in the support structure should be sealed. See details in Figures 19 and 20.
10. Emergency discharge quick-release devices should be provided in large reservoirs (20-30 MG).
11. Wind problems with exposed thin membrane liners can be controlled by installing vents built into the lining. See details in Appendix F.
12. Adequate protective fencing must be installed to control vandalism.

Table 15. Lining selection guide chart[a,b] (Kays, 1977).[d]

Substance	Type of Lining										
	PE	Hypalon	PVC	Butyl Rubber	Neoprene	Asphalt Panels	Asphalt Concrete	Concrete	Steel	CPE	3110
Water	OK	OK	OK	OK	OK	OK	OK	OK	CP	OK	OK
Animal oils	OK[c]	OK	ST	OK	OK	Q	Q	NR	OK	OK	OK
Petroleum oils (no aromatics)	OK[c]	Q	NR	NR	SW	NR	NR	OK	OK	OK	OK
Domestic sewage	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Salt solutions	OK	OK	OK	OK	OK	OK	Q	NR	NR	OK	OK
Base solutions	OK	OK	OK	OK	OK	OK	OK	Q	OK	OK	OK
Mild acids	OK	OK	OK	OK	QK	OK	OK	NR	NR	OK	OK
Oxidizing acids	NR	NR	NR	NR	Q	NR	NR	NR	NR	NR	NR
Brine	OK	OK	OK	OK	OK	OK	OK	Q	NR	OK	OK
Petroleum oils (aromatics)	Q	NR	NR	NR	NR	NR	NR	OK	OK	NR	NR

[a] OK = generally satisfactory, Q = questionable, NR = not recommended, ST = stiffens, SW = swells, CP = cathodic protection suggested.

[b] It is recommended that immersion tests be run on any lining being considered for use in an environment where a question exists concerning its longevity. Consult the lining manufacturer or an experienced testing laboratory when in doubt.

[c] Must be a one piece lining.

[d] Courtesy of John Wiley & Sons, Inc., New York, N.Y.

the presence of water. Different ways in which bentonite may be used to line lagoons are listed below.

(a) A suspension of bentonite in water (with a bentonite concentration approximately 0.5 percent of the water weight) is placed over the area to be lined, and the bentonite settles to the surface forming a thin blanket.

(b) The same procedure as (a), except frequent harrowing of the surface produces a uniform soil bentonite mixture on the surface of the soil. The amount of bentonite used in this procedure is approximately 1 lb/ft^2 of soil.

(c) A gravel bed approximately 6 in. deep is first prepared and the bentonite application performed as in (a). The bentonite will settle through the gravel layer and seal the void spaces.

(d) Bentonite is spread as a membrane 1 or 2 in. thick and covered with an 8 to 12 in. blanket of earth and gravel to protect the membrane. A mixture of earth and gravel is more satisfactory than soil alone, because of the stability factor and resistance to erosion.

(e) Bentonite is mixed with sand at approximately 1 to 8 volume ratio. The mixture is placed in a layer (approximately 2 to 4 in. in thickness) on the reservoir bottom and covered with a protective cover. This method takes about 3 lb/ft^2 of bentonite (Rollins and Dilla, 1970).

In methods (d) and (e) above, certain construction practices are recommended. They are as follows:

1. The section must be overexcavated (1 ft or more) with drag lines or graders.
2. Side slopes should probably be not steeper than 2 to 1.
3. Subgrade surface should be dragged to remove large rocks and sharp angles. Normally 2 passes with adequate equipment are sufficient to smooth the subgrade.
4. Subgrade should be rolled with a smooth steel roller.
5. The subgrade should be sprinkled to eliminate dust problems.
6. A membrane of bentonite or soil bentonite should then be placed.
7. The protective cover should contain sand and small gravel, in addition to cohesive, fine grained material so that it will be erosion resistant and stable.

The performance of bentonite linings is greatly affected by the quality of the bentonite. Some bentonite deposits may contain quantities of sand, silt and clay impurities. Wyoming type bentonite, which is a high swelling sodium montmorillonite clay has been found to be very satisfactory. Fine ground bentonite is generally more suitable for the lining than pit run bentonite. If the bentonite is finer than a No. 30

sieve, it may be used without specifying size gradation. But if the material is coarser than the No. 30 sieve, it should be well graded. Bentonite should usually contain a moisture content of less than 20 percent. This is especially important for thin membranes. Some disturbance and possibly cracking of the membranes may take place during the first year after construction due to settlement of the subgrade upon saturation. A proper maintenance program, especially at the end of the first year, is necessary (USDI, 1968). Examples of the application of bentonite in sealing various types of reservoirs are presented in Appendix D.

Asphalt. Asphalt linings may be buried or surface and may be composed of asphalt or a prefabricated asphalt. Some possibilities are as follows:

A. An asphalt membrane is produced by spraying asphalt at high temperatures. This lining may be either on the surface or buried. A large amount of special equipment is needed for installation. Useful lives of 18 years or greater have been observed when these membranes are carefully applied and covered with an adequate layer of fine grained soil.

B. Asphaltic Membrane Macadam. This is similar to the asphaltic membrane, but it is covered with a thin layer of gravel penetrated with hot blown asphalt cement.

C. Buried Asphaltic Membrane. This is similar to A, except a gravel-sand cover is applied over the asphaltic membrane. This cover is usually more expensive than cover in B and less effective in discouraging plant growth.

D. Built Up Linings. These include several different types of materials. One type could be a fiber glass matting, which is applied over a sprayed asphalt layer and then also sprayed or broomed with a sealed coat of asphalt or clay. A 10 ounce jute burlap has also been used as the interior layer between 2 hot sprayed asphalt layers. In this case the total asphalt application should be about 2.5 gal/yd^2. The prefabricated lining may be on the surface or buried. If buried, it could be covered with a layer of soil or, in some cases, a coating of Allox, which is a stabilized asphalt, is used (USDA, 1972).

E. Prefabricated Linings. Prefabricated asphalt linings consist of a fiber or paper material coated with asphalt. This type of liner has been used exposed and covered with soil. Joints between the material have an asphaltic mastic to seal the joint. When the asphaltic material is covered, it is more effective and durable. When it is exposed it should be coated with aluminized paint every 3 to 4 years to retard degradation. This is necessary especially above the water line. Joints also have to be maintained when not covered with fine grained soil. Prefabricated asphalt membrane lining is approximately 1/8 to

1/4 in. thick. It may be handled in much the same way as rolled roofing with lapped and cemented joints. Cover for this material is generally earth and gravel, although shotcrete and macadam have been utilized.

Installation procedures for prefabricated asphalt membrane linings and for buried asphalt linings are similar to those stated for buried bentonite linings. The preparation of the subgrade is important and it should be stable and adequately smooth for the lining. Applications of this material are shown in Appendix E.

Soil Cement Linings. Best results are obtained with soil cement when the soil mixed with the cement is sandy and well graded to a maximum size of about 3/4 in. Soil cement should not be placed in cold weather and it should be cured for about 7 days after placing. Some variations of the soil cement lining are listed below:

A. Standard soil cement is compacted using a water content of the optimum moisture content of the soil. The mixing process is best accomplished by traveling mixing machines and can be handled satisfactorily in slopes up to 4 to 1. Standard soil cement may be on the surface or buried.

B. Plastic soil cement (surface or buried) is a mixture of soil and cement with a consistency comparable to that of Portland cement concrete. This is accomplished by adding a considerable amount of water. Plastic soil cement contains from 3 to 6 sacks of cement/yd^3 and is approximately 3 in. thick.

C. Cement modified soil contains 2 to 6 percent volume of cement. This may be used with plastic fine grained soils. The treatment stabilizes the soil in sections subject to erosion. The lining is constructed by spreading cement on top of loose soil layers by a fertilizer type spreader. The cement is then mixed with loose soil by a rotary traveling mixer and compacted with a sheeps foot roller. The 7 day curing period is also necessary for a cement modified soil.

Cost of Linings

The cost of linings for lagoons and reservoirs are approximations at best and have been estimated based on values in specific jobs several years ago. A factor of 15 percent per year for inflation is estimated and the costs are based on that rate.

Bentonite linings cost approximately \$1 to \$2/yd^2 when applied on the surface. The greater cost will occur for harrowed blankets. Buried blankets cost approximately \$2.50/yd^2.

The average cost of buried asphalt membrane linings with adequate cover is about \$3.50/yd^2.

Prefabricated asphalt materials are generally cheaper than buried asphalt membrane linings if the prefabricated material can be obtained for less than \$0.90/yd^2.

Cover material over buried membranes composes the most expensive part of the placing procedure. The cover materials should, therefore, be as thin as possible and still provide adequate protection for the membrane. If a significant current is present in the pond, the depth of coverage should be greater than 10 in., and this minimum depth should only be used when the material is erosion resistant and also cohesive. Such a material as a clayey gravel is suitable. If the material is not cohesive, or if it is fine grained, a higher amount of cover is needed (USDI, 1963).

Maintenance costs for different types of linings are difficult to estimate. Maintenance should include repair of holes, cracks and deterioration, weed control expenses and animal damages and damages caused by cleaning the pond, if that is necessary. Climate, type of operation, type of terrain and surface conditions also influence maintenance costs.

Plastic soil cement containing from 3 to 6 sacks of cement/yd^3 and approximately 3 in. thick costs about \$3.00/yd^2.

Evaluation of Linings

Bentonite linings may be effective if the sodium bentonite used has an adequate amount of exchangeable sodium. Deterioration of the linings has been observed to occur in cases where magnesium or calcium has replaced sodium as absorbed ions. A layer of bentonite on the soil surface tends to crack if allowed to dry and is, therefore, usually placed as a blanket of bentonite soil mixture with a cover of fine grained soil on top, or as a thicker layer, 6 in. or more, of a soil bentonite material (Dedrick, 1975). Surface bentonite cannot be expected to be effective longer than 2 to 4 years. A buried bentonite blanket may last from 8 to 12 years.

The quality of the bentonite used is a primary consideration in the success of bentonite membranes. Poor quality bentonite deteriorates rapidly in the presence of hard water, and it also tends to erode in the presence of currents or waves. Bentonite linings must often be placed by hand and this is a costly procedure in areas of high labor costs.

Seepage losses through buried bentonite blankets are approximately 0.7 to 0.85 ft^3/ft^2/day. This figure is for thin blankets and represents about a 60 percent improvement over ponds with no lining.

Linings of bentonite and asphalt are sometimes unsuitable in areas of high weed growth, since weeds and tree roots puncture the material readily (USDI, 1963).

Many lining failures occur as a result of rodent and crayfish holes in embankments. Asphalt membrane lining tends to decrease the damage, but in some cases, hard surface linings are necessary to prevent water loss from embankment failures.

Linings of hot applied buried asphalt membrane provide one of the tightest linings available. These linings deteriorate less than other flexible membrane linings (USDI, 1963).

Asphalt linings composed of prefabricated buried materials are best for small jobs, since the amount of special equipment and labor connected with installation is a minimum. For larger jobs sprayed asphalt is more economical.

When fibers and fillers are used in asphalt membranes, there is a greater tendency to deteriorate when these fillers are composed of organic materials. Inorganic fibers are, therefore, more useful (USDI, 1963). Typical volume of seepage through one buried asphalt membrane after 10 years of service was consistently 0.08 $ft^3/ft^2/day$ (USDI, 1968).

Asphalt membrane linings can be constructed at any time of year, and since it is usually convenient in canals and ponds to use the late fall and winter seasons for installing lining, this may dictate the buried asphalt membrane lining as the proper one to use in many cases (USDI, 1963).

Buried asphalt membranes in general perform satisfactorily for more than 15 years. When these linings fail, it is generally due to one or more of the following causes:

A. Placement of lining on unstable side slopes
B. Inadequate protection of the membrane
C. Weed growth
D. Surface runoff
E. Type of subgrade material
F. Cleaning operations
G. Scour of cover material
H. Membrane puncture

Soil cement has been used successfully in some cases in mild climates. Where wetting or drying is a factor, or if freezing-thawing cycles are present, the lining will deteriorate rapidly (USDI, 1963).

Thin Membrane Liners

Plastic and elastomeric membranes are popular in applications requiring essentially zero permeability. These materials are economical, resistant to most chemicals if selected and installed properly, available in large sheets simplifying installation, and essentially impermeable. As discharge standards continue to become more stringent, the application of plastic and elastomeric membranes as lagoon liners will increase because of the need to guarantee protection against seepage. This is particularly true in the sealing of lagoons containing toxic wastewaters or the sealing of landfills containing toxic solids and sludges.

Typical standards being developed to control the application of liners are presented in Appendixes A and B. A partial listing of the trade names, product description and manufacturer of plastic and elastomer lining materials is presented in Appendix C. Properties of the synthetic flexible liners were presented in Table 4 in the Literature Review section. The summary of effective design practices presented in Table 14 is applicable to synthetic liners.

Design Details

The most difficult design problem encountered in liner applications involves placing a liner in an existing reservoir (lagoon). Effective design practices are essentially the same as those used in new systems, but additional care must be exercised in the evaluation of the existing structure and the required results. Lining materials must be selected so that compatibility is obtained. For example, a badly cracked concrete lining to be covered with a flexible synthetic material must be properly sealed and placed in such a way that additional movement will not destroy the new liner. Sealing around existing columns, footings, etc. are other examples of items to be considered.

The following paragraphs are a condensation of the discussion by Kays (1977) of effective design practices which have been summarized in Table 14. Emphasis is placed on the details describing the installation of plastic or elastomeric materials.

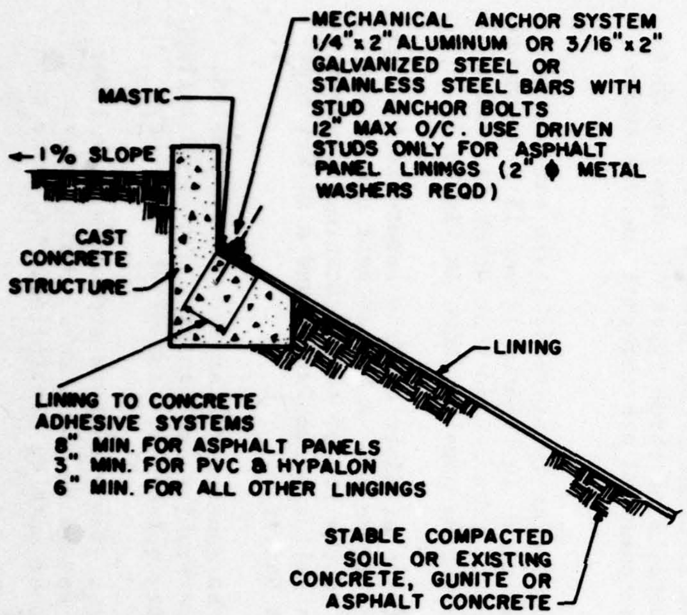
Top Slope Anchor. Formal and informal anchor systems are used at the top of the slope of dikes. Details of three types of formal anchors are presented in Figures 9-11. Recommended are informal anchors shown in Figures 12 and 13.

Inlet-Outlet Seals. When the lining is pierced, seals can be made in two ways. The techniques illustrated in Figures 14 and 15 are commonly used, and the second technique utilizes a pipe boot which is sealed to the liner and clamped to the entering pipe as shown in Figure 16.

It is recommended that inlet-outlet pipes enter a reservoir through a structure such as that shown in Figure 17. A better seal can be produced when the liner is attached to the top of the structure. However, such an arrangement can result in solids accumulation and a direct free entry into a wastewater lagoon is better.

A drain near the outlet can be constructed as shown in Figure 18. As mentioned in Table 14, large reservoirs containing above 20-30 million gallons should be equipped to empty quickly in case of an emergency.

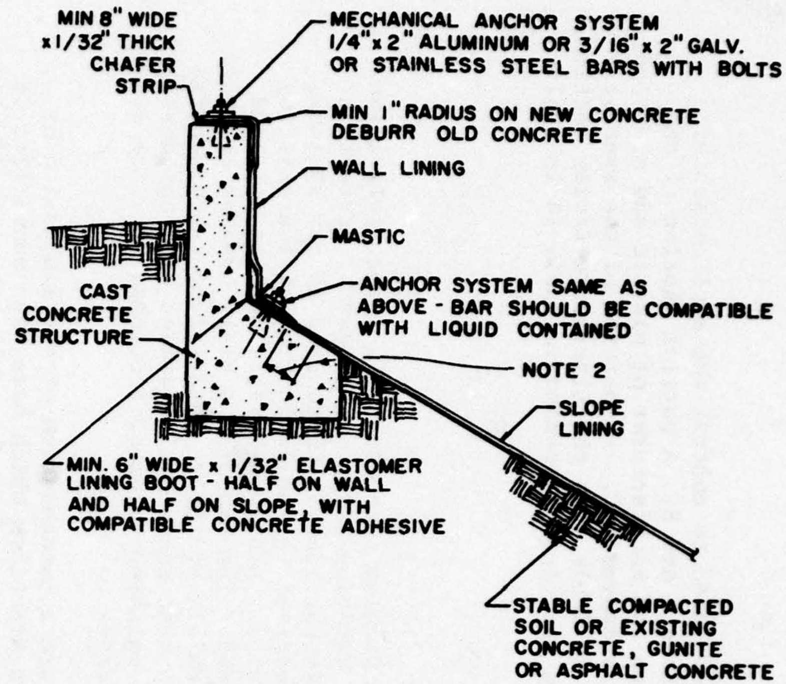
Cracks and Imperfection Seals. The structure supporting the liner must be smooth enough to prevent damage to the liner. Rocks, sharp protrusions and other rough surfaces must be controlled. In areas with



NOTE

1. TOP OF CONCRETE SHOULD BE SMOOTH AND FREE OF ALL CURING COMPOUNDS.
2. USE MIN 1/32"x 2" GASKET (MAT'L COMPATIBLE WITH LINING) BETWEEN BAR AND LINING, EXCEPT NO GASKET REQUIRED FOR ASPHALT PANELS OR OTHER LININGS THICKER THAN .040".

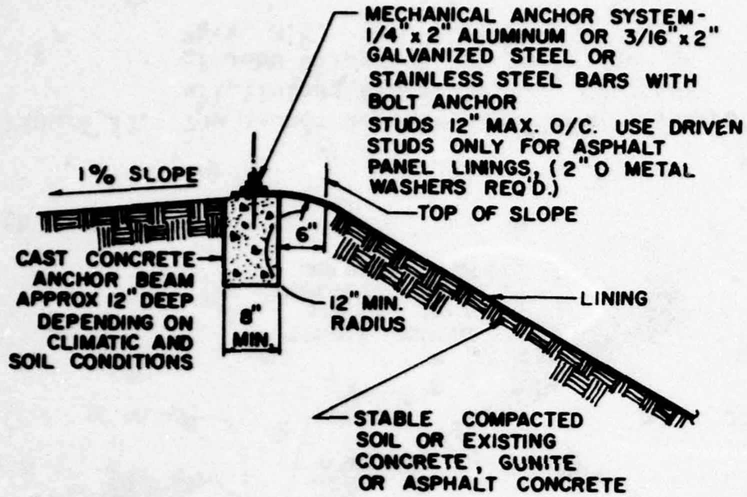
Figure 9. Top anchor detail--alternative 1, all linings (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.



NOTE

1. ALL CONCRETE AT SEALS SHALL BE SMOOTH AND FREE OF ALL CURING COMPOUNDS.
2. USE COMPATIBLE ADHESIVE BETWEEN SLOPE LINING AND ELASTOMER BOOT, AND 3" MIN. WIDTH OF COMPATIBLE ADHESIVE BETWEEN SLOPE LINING AND CONCRETE.

Figure 10. Top anchor detail--alternative 2, all linings (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.



NOTE

1. TOP OF CONCRETE SHOULD BE SMOOTH AND FREE OF ALL CURING COMPOUNDS.

2. USE MIN. 1/32"x2" GASKET (MAT'L COMPATIBLE WITH LINING) BETWEEN BAR & LINING EXCEPT NO GASKET REQUIRED FOR ASPHALT PANELS OR OTHER LININGS THICKER THAN .040"

Figure 11. Top anchor detail--alternative 3, all linings (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.

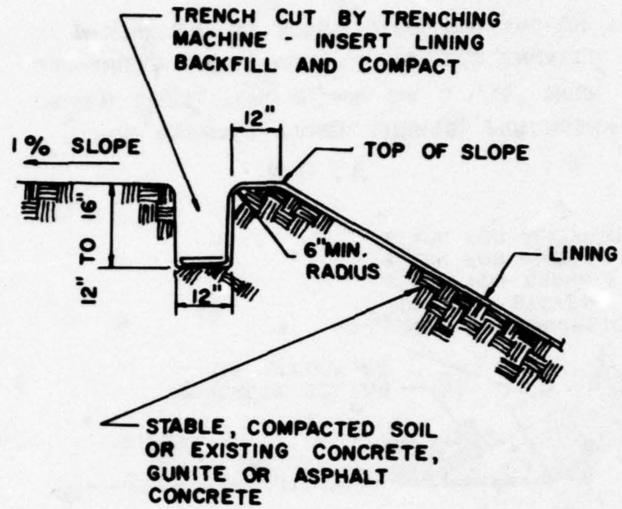


Figure 12. Top anchor detail--alternative 4, all linings except asphalt panels (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.

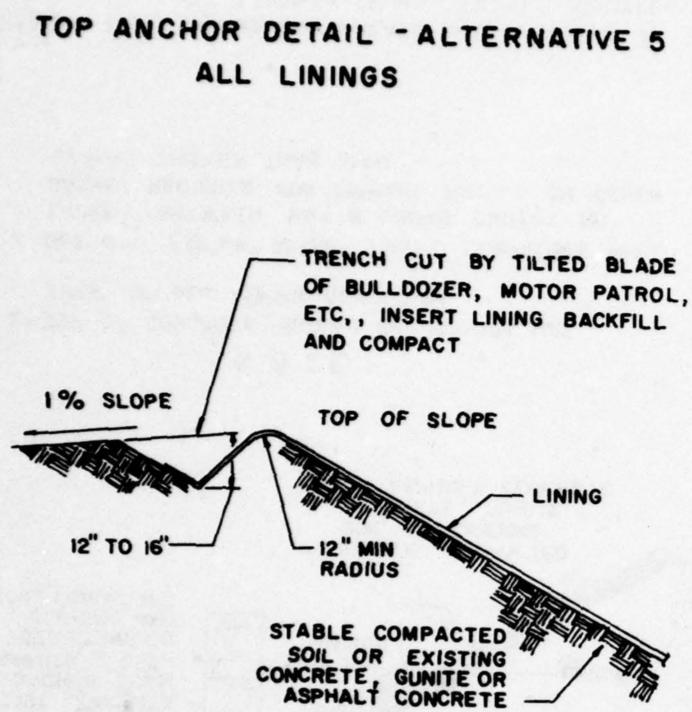


Figure 13. Top anchor detail--alternative 5, all linings (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.

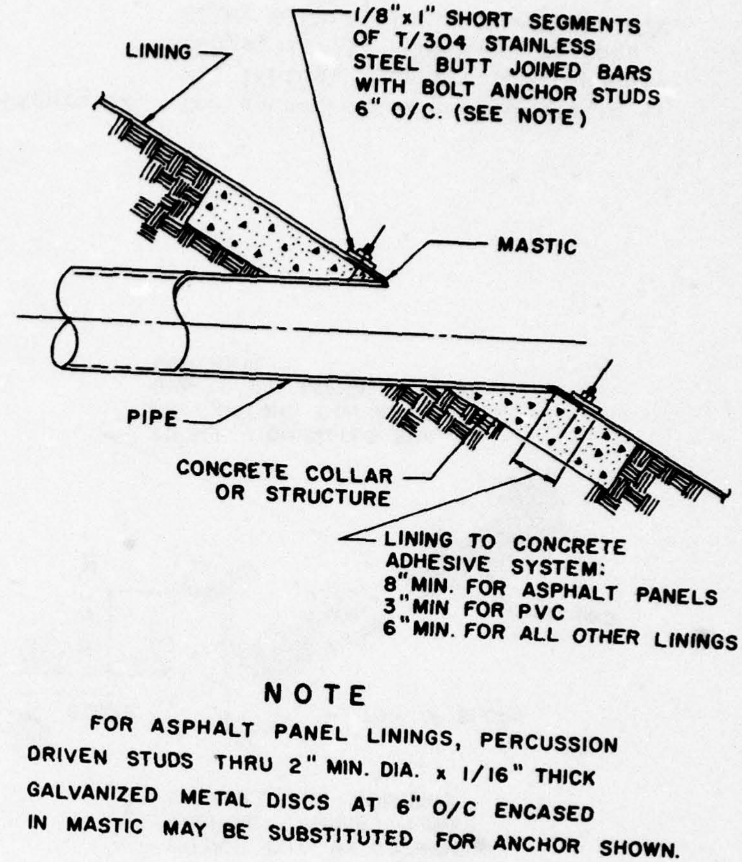


Figure 14. Seal at pipes through slope, all linings (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.

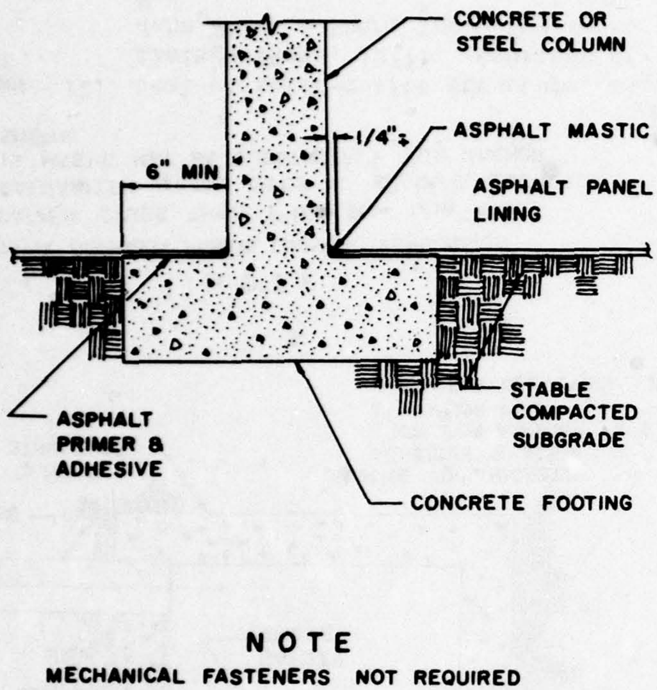


Figure 15. Seal at floor columns, asphalt panels (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.

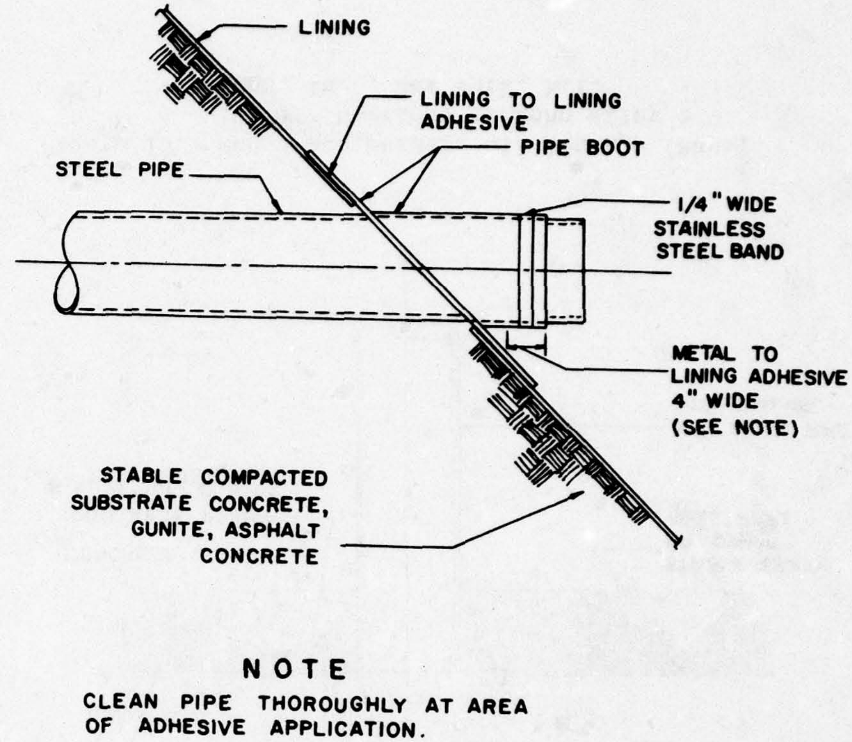
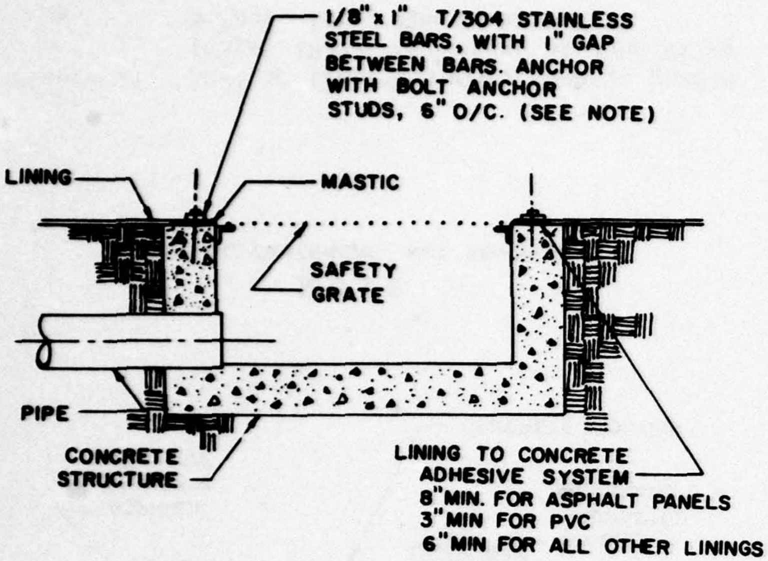


Figure 16. Pipe boot detail, all linings except asphalt panels (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.



NOTE

WITH ASPHALT PANEL LININGS, PERCUSSION DRIVEN STUDS THRU 1" MIN DIA 1/16" THICK GALVANIZED METAL DISCS AT 6" O/C, ENCASED IN MASTIC MAY BE SUBSTITUTED FOR ANCHOR SHOWN.

Figure 17. Seal at inlet-outlet structure, all linings (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.

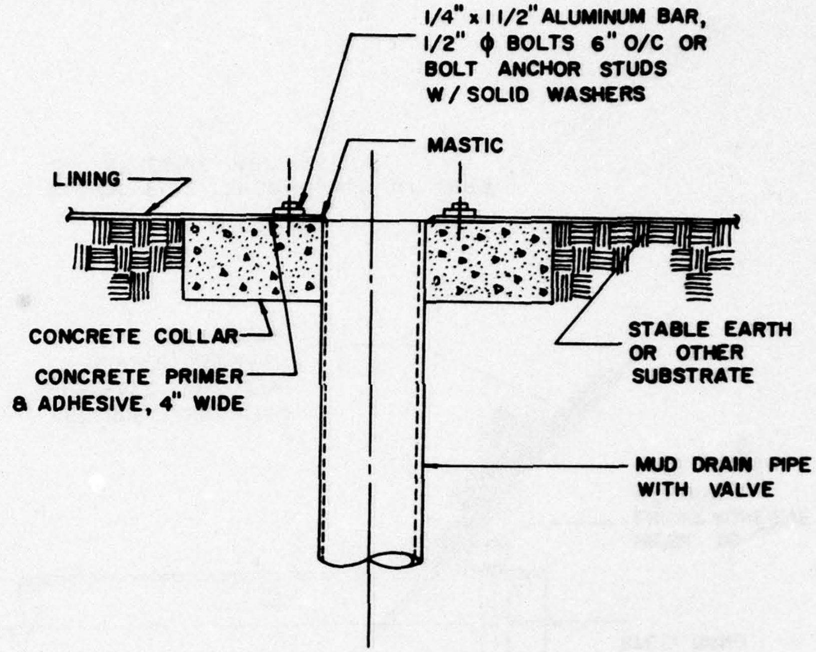


Figure 18. Mud drain detail, all linings (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.

particularly rough surfaces, it may be necessary to add padding to protect the liner. Cracks can be repaired as shown in Figures 19 and 20.

Wind and Gas Control. Thin membrane liners may have problems with wind on the leeward slopes. Vents built into the lining control this problem as well as serve as an outlet for gases trapped beneath the liner. Details of such a venting system are shown in Appendix F.

Fencing. Protection of a thin membrane lining is essential, and Kays (1977) recommends that the fence be at least 6 feet high and be placed on the outside berm slope with the top of the fence below the top elevation of the dike.

Proprietary Products and Recommended Procedures

A partial listing of the manufacturers of plastic and elastomeric liners is presented in Appendix C. In addition to these manufacturers, there are many firms specializing in the installation of lining materials. Most of the installation companies and the manufacturers publish specifications and installation instructions and design details for use by customers and design engineers. Most of the recommendations by the manufacturers and installers are similar, but there are differences worthy of consideration when designing a system requiring a liner.

It would be impractical to reproduce all of the publications available; therefore, only a selected few are presented as appendixes. Information and instruction bulletins were selected for inclusion as appendixes based principally on the type of material although some firms install many types of liners.

Appendixes F through I contain many valuable suggestions for the proper selection and installation of a liner. The information presented in these appendixes should be used with caution and only after consultation with the firms preparing the information.

The liner described in Appendix J was developed for protection of water supplies and other liquids requiring protection from the elements and birds and animals. This type of liner has potential as an odor control device in small wastewater treatment systems. It would be particularly applicable to small anaerobic systems or in cases where it is desirable to control light penetration.

New products continue to be developed, and with each new material the options available to designers continue to improve. The future should bring even more versatile and effective liners to select for seepage control. If care and common sense are applied to the application of existing and new materials, the control of seepage pollution should become a minor problem of the future.

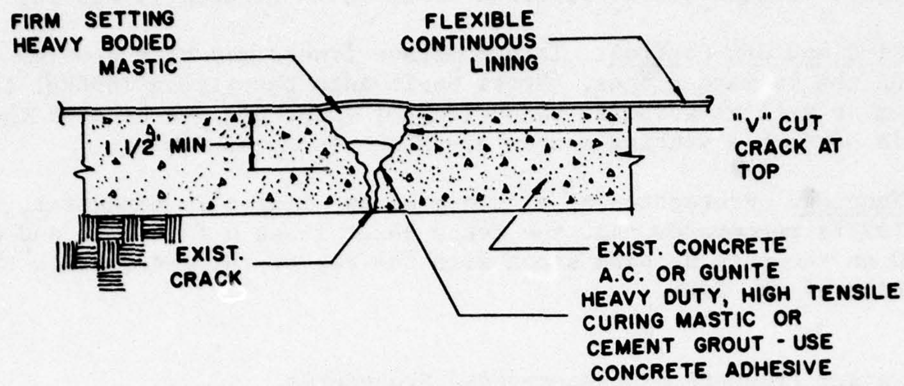


Figure 19. Crack treatment--alternative A (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.

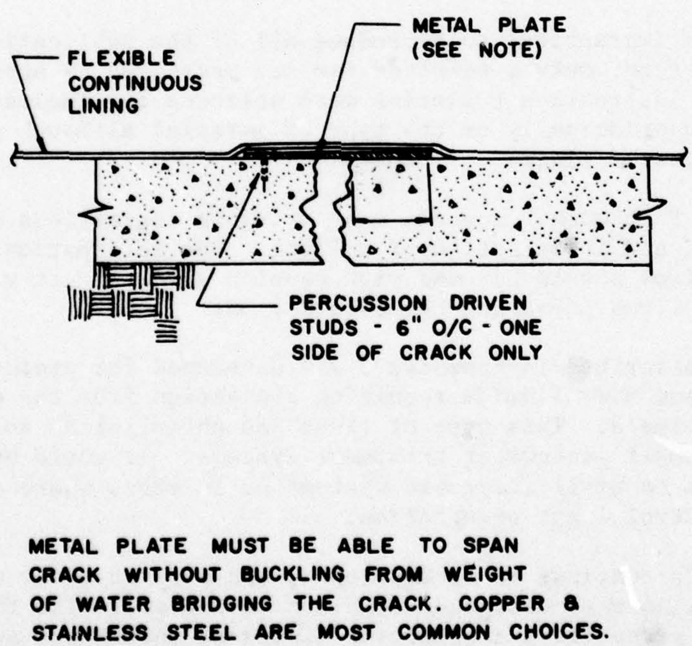


Figure 20. Crack treatment--alternative B (Kays, 1977). Courtesy of John Wiley & Sons, Inc., New York, N.Y.

CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of the literature review, the following conclusions and recommendations can be made.

1. The design and construction of liners should be carried out by trained, experienced professionals.

2. Multiple options exist for designers of lagoon liners, and the proper selection and installation procedures should result in satisfactory liners.

3. Little information exists on the natural sealing of wastewater stabilization lagoons. Most results are based on speculation from observations instead of carefully planned experiments designed to evaluate the phenomenon of soil sealing.

4. The mechanisms involved in natural sealing of lagoon bottoms should be evaluated. Controversy exists as to whether or not reductions in seepage rates are attributable to natural sealing. Mounding of groundwater beneath the lagoon has been credited with much of the reduction in seepage.

5. Most reported seepage rates and the effectiveness of various liner materials are secondary to other aspects of experiments and are incomplete and limited in value.

6. A need exists for accurate measurements of seepage rates and the effectiveness of various lining materials.

7. An accurate, reproducible method of measuring seepage from lagoons is needed.

8. The success of a particular lining material is dependent upon the characteristics of the waste contained, the design details, and the construction techniques.

9. Failure of linings is most often attributable to poor judgment in selection, installation or operation of a lagoon and not to the lining material.

10. An assessment of the permeability of all lining materials in actual installations is needed.

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APPENDIX A

STATE OF WASHINGTON LAGOON LINER REQUIREMENTS[1]

15.4 Pond Construction Details

15.41 Liners

15.411 Requirement for Lining

The seepage rate through the lagoon bottom should not exceed 1/4 inch per day. Liners are required if native soils will not ensure this.

15.412 General

Systems utilizing soil, bentonite, or synthetic liners may be considered, provided the permeability, durability, integrity, cost-effectiveness, etc., of the proposed material can be satisfactorily demonstrated. Results of a testing program that substantiates the adequacy of the proposed liner must be incorporated into and/or accompany the engineering report. Standard ASTM procedures or acceptable similar methods should be used for all tests.

As a final field determination of the quality of all in-place liners, ponds should be prefilled and checked for seepage.

Schematics for each of the three basic liners are attached for information.

15.413 Soil Liners (Figure 6)

Preliminary testing of proposed soil liners should include examination of the factors affecting seepage through the seal, such as type of soil, water content, density, thickness, etc., and determination of the seepage rate through the proposed seal.

Specifications for a soil liner should be based upon results of the preliminary testing program and at a minimum provide the type of soil, optimum and acceptable range in water content, and maximum allowable boulder size. Recommended requirements include (1) the soil should have a high and uniform fines (clays and silts) content, (2) the water content should be at or up to 4 percent above the optimum for maximum compaction, and (3) boulder size should not exceed 4 inches.

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[1]Taken from "Manual of Standards for Sewage Works Design" prepared by Water Quality Management Section, Department of Ecology, State of Washington, Olympia, Washington.

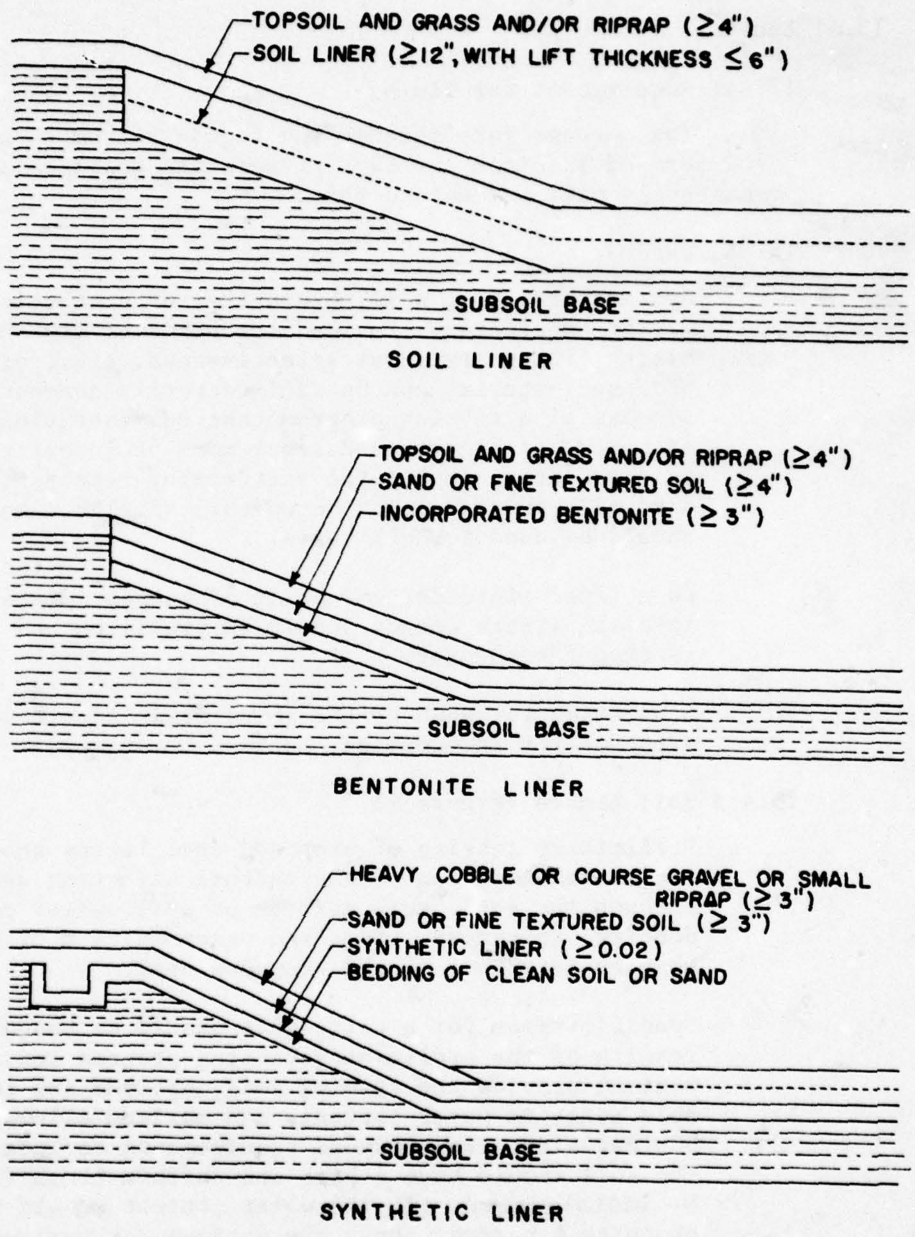

Figure 6. Cross sections of liners.

Specifications for construction and/or placement of a soil seal should be based upon results of a preliminary testing program. As a minimum they should provide for sealing of dikes prior to pond bottom and specify seal density and thickness and number of lifts. Recommended requirements include (1) the liner should be compacted at the proper water content to at least 90 percent of Standard Proctor Density, (2) the liner should be at least 12 inches thick and applied in lifts no greater than 6 inches, (3) the completed liner should be maintained at or above the optimum water content until the pond is prefilled, and (4) dike liners should be covered as described under Embankment and Dikes.

Construction and/or placement of the soil liner should be inspected and tested to ascertain compliance with specifications. Written certification that the soil liner was constructed in accordance with specifications should be provided by the project engineer or an independent soils laboratory. Tests for water content and density should be taken during application of each lift. Additionally, either permeability testing of undisturbed core samples from the in-place seal, or detailed tests such as particle size distribution and Atterburg limits confirming that the soil used in liner construction was the same soil initially tested, should be provided. In all cases, at least one test should be provided per acre per lift, except for core sampling of the in-place liner, where one core of the completed liner should be tested per acre.

15.414 Bentonite Liners (Figure 6)

Preliminary testing of proposed bentonite liners should include, in addition to the tests outlined for soil liners, an examination of the type and rate of bentonite being considered.

Specifications for the bentonite liner should be based upon results of the preliminary testing program and at a minimum provide the types of soil, type of bentonite, bentonite application rate, and optimum and acceptable range in water content of the soil-bentonite mixture. Recommended requirements include (1) the bentonite should be high-swelling and free-flowing and have a particle size distribution favorable for uniform application and minimizing of wind drift, (2) the application rate should be at least 125 percent of the minimum rate found to be adequate in laboratory tests, (3) application rates recommended by a supplier should be confirmed by an independent laboratory, and (4) the water

content of the soil-bentonite mixture should be at or up to 4 percent above the optimum for maximum compaction.

Specifications for construction and/or placement of a bentonite liner should be based upon results of the preliminary testing program and at a minimum provide lining of dikes prior to bottom, bentonite application procedures, seal density, covering of the seal, and prehydration of the bentonite. Recommended requirements include (1) bentonite should be applied with specifically designed spreading equipment, (2) application should be split so that one-half is applied in one direction and the other half in a perpendicular direction, (3) the bentonite should be mixed into the soil to a uniform depth of at least 3 inches, (4) the liner should be compacted at the proper water content to at least 90 percent of Standard Proctor Density (specifically excluding use of a sheepsfoot roller), (5) the completed seal should be covered with at least 4 inches of soil in addition to necessary erosion control, and (6) the completed liner should be hydrated with fresh water prior to introduction of wastewater and kept at or above the optimum water content until the pond is prefilled.

The bentonite supplier or its representative should verify that the specifications are in accordance with its recommendations, and written certification that the liner was provided and applied in accordance with specifications should be furnished by the supplier, project engineer, or independent soils laboratory. The actual bentonite application rate and the water content and density should be tested during liner construction. Permeability testing of undisturbed core samples should be provided following seal completion. At least one test per acre is recommended in all cases.

15.415 Synthetic Liners (Figure 6)

Requirements for thickness of synthetic liners may vary due to liner material, but it is generally recommended that the liner thickness be no less than .020 inch or 20 mil. Such thickness provides a safety factor which will reduce the probability of puncture. Consideration should also be given to liners containing reinforcing in appropriate situations, such as sidewall slopes steeper than 3:1 or pond depths greater than 6 feet. Special care must be taken to select the appropriate material to perform under existing conditions.

Proper site preparation for synthetic liners is essential. The subsoil bed should be sufficiently prepared to ensure that all holes, rocks, stumps, and other debris are eliminated. The subsoil should be sieved or the area raked after grading to provide a smooth, flat surface free of stones and other sharp protrusions that could damage the liner. If the subsoil contains sharp, nonremovable objects, a bedding of 2 to 4 inches of clean soil or sand should be provided. Soil should be well compacted and sterilized to kill vegetation. Four-inch perforated pipe should be strategically placed to allow venting and draining of the soil to reduce gas and hydrostatic pressures and to facilitate monitoring for leakage. The pipe should be installed in trenches sloping toward a sump and be backfilled with pea gravel or other coarse material.

Liner panels should be laid out in a longitudinal direction with an overlap of 4 to 6 inches. Careful application of the appropriate adhesive is essential.

The anchor trench should be a minimum 6-inch depth and be placed at least 9 to 12 inches beyond the slope break at the dike. Care must be exercised in the backfilling of the anchor trench to ensure the liner is not damaged.

To prevent erosion, mechanical damage to the liner, and hydraulic lifting of the liner, a minimum backfill of 6 inches on top of the liner is recommended. On the side slopes this should consist of a minimum 3-inch primary fill of sand or finely textured soil and a minimum 3-inch secondary fill of heavier cobble, coarse gravel, or small riprap. On the bottom the backfill may consist solely of the sand or finely textured soils.

The manufacturer's representative should supervise or conduct all phases of installation. It is also recommended that installation be done by contractors familiar with potential problems that can be encountered.

APPENDIX B

STATE OF MINNESOTA LAGOON LINER REQUIREMENTS[1]

94.2 Pond Bottom

94.21 Soil Soil used in constructing the pond bottom (not including seal) and dike cores shall be relatively incompressible and tight and compacted at or up to 4 percent above the optimum water content to at least 90 percent Standard Proctor Density.

94.22 Seal Ponds shall be sealed such that seepage loss through the seal is as low as practically possible. Seals consisting of soils, bentonite, or synthetic liners may be considered provided the permeability, durability, integrity and cost-effectiveness of the proposed material can be satisfactorily demonstrated for anticipated conditions. Results of a testing program which substantiates the adequacy of the proposed seal must be incorporated into and/or accompany the engineering report. Standard ASTM procedures or acceptable similar methods shall be used for all tests.

To achieve an adequate seal in systems using soil or bentonite seal materials, the coefficient of permeability (K) in centimeters per second specified for the seal shall not exceed the value derived from the following expression:

$$K \leq 2.58 \times 10^{-9}(L)$$

where L equals the thickness of the seal in centimeters.

For a seal consisting of a synthetic liner, seepage loss through the liner shall not exceed the quantity equivalent to seepage loss through an adequate soil seal.

In addition to the specific quality control tests specified for each type of seal in the following three sections, all ponds should be prefilled (See Section 94.24) and checked for seepage as a final field determination of the quality of in-place seals.

Schematics of each of the three basic seal systems are attached for information.

94.221 Soil Seals (Figure 4)

a. Preliminary testing of proposed soil seals shall include examination of the factors affecting seepage through the seal such as type(s) of soil, water content, density, thickness, etc. and determination of the coefficient of permeability for proposed seal.

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[1]Taken from revised manual "Recommended Standards for Sewage Works" prepared by Minnesota Pollution Control Agency, Roseville, Minnesota.

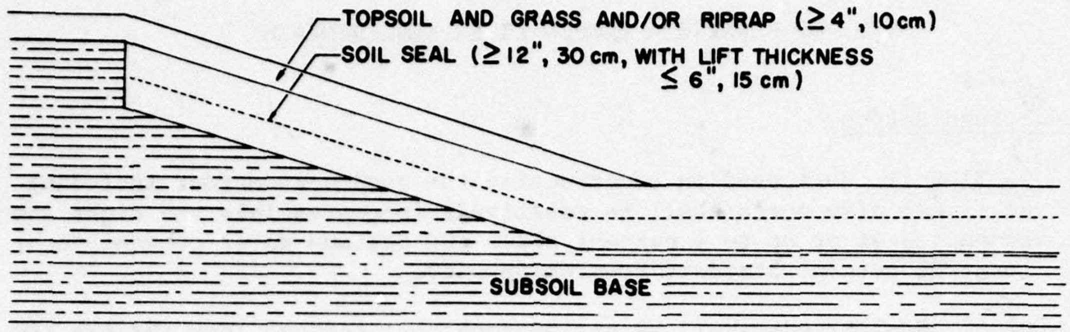


Figure 4. Cross-section of pond sealed with soil (Section 94.221)

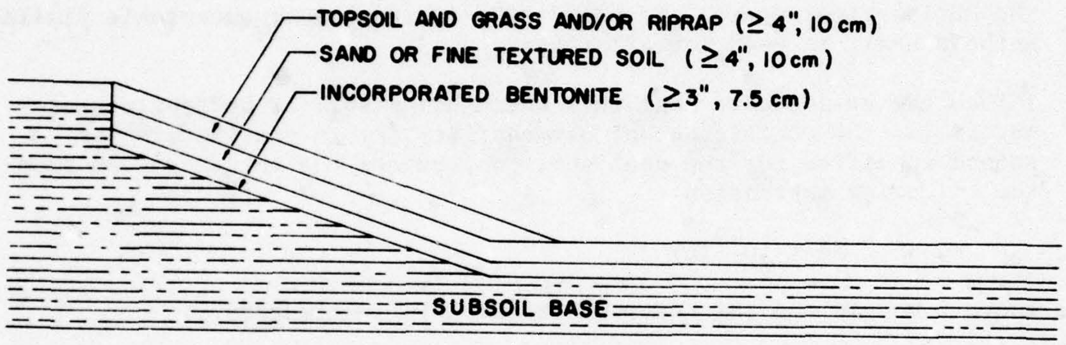


Figure 5. Cross-section of pond sealed with bentonite (Section 94.222)

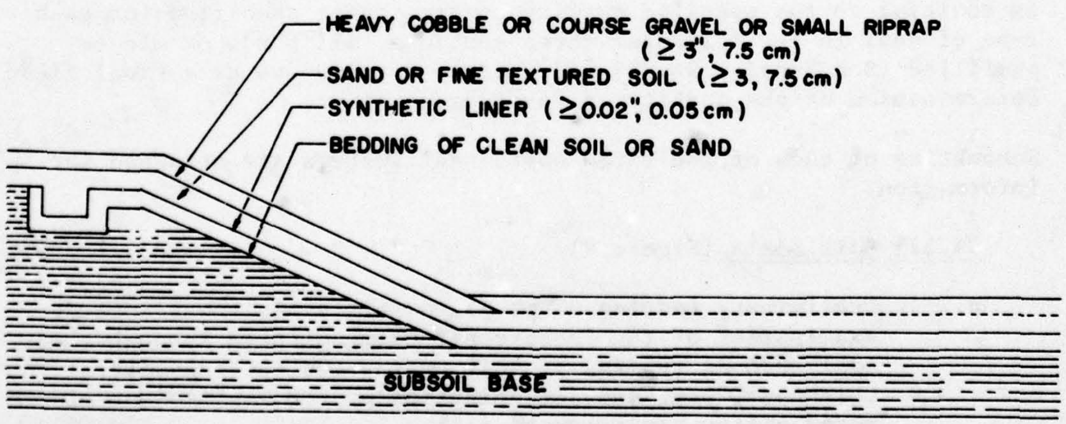


Figure 6. Cross-section of pond sealed with synthetic liner (Section 94.223)

b. Specifications for a soil seal shall be based upon results of the preliminary testing program and at a minimum provide the type(s) of soil, optimum and acceptable range in water content, maximum coefficient of permeability, and maximum allowable boulder size. Recommended requirements include: (1) the soil shall have a high and uniform fines (clays and silts) content; (2) the water content shall be at or up to 4 percent above the optimum for maximum compaction; (3) the coefficient of permeability shall not exceed the value derived in Section 94.22; and (4) boulder size shall not exceed four inches (10 centimeters).

c. Specifications for construction and/or placement of a soil seal shall be based upon results of a preliminary testing program. As a minimum they shall provide for sealing of dikes prior to pond bottom and specify seal density and thickness and number of lifts. Recommended requirements include: (1) the seal shall be compacted at the proper water content to at least 90 percent of Standard Proctor Density; (2) the seal shall be at least 12 inches (30 centimeters) thick and applied in lifts no greater than six inches (15 centimeters); (3) the completed seal shall be maintained at or above the optimum water content until the pond is prefilled in accordance with 94.24; and (4) dike seals shall be covered as specified in 94.17.

d. Construction and/or placement of the soil seal shall be inspected and tested to ascertain compliance with specifications. Written certification that the soil seal was constructed in accordance with specifications shall be provided by the project engineer or an independent soils laboratory. Tests for water content and density shall be taken during application of each lift. Additionally, either permeability testing of undisturbed core samples from the in-place seal, or detailed tests such as particle size distribution and Atterburg limits confirming the soil used in seal construction was the same soil initially tested shall be provided. In all cases, at least one test shall be provided per acre per lift (two tests per hectare per lift), except for core sampling of the in-place seal where one core of the completed seal shall be tested per acre (two cores per hectare).

<u>94.222 Bentonite Seals</u> (Figure 5)

a. Preliminary testing of proposed bentonite seals shall include, in addition to the tests outlined in 94.221a, an examination of the type and rate of bentonite being considered.

b. Specifications for the bentonite seal shall be based upon results of the preliminary testing program and at a minimum provide the type(s) of soil, type of bentonite, bentonite application rate, optimum and acceptable range in water

content of the soil-bentonite mixture and maximum coefficient of permeability. Recommended requirements include: (1) the bentonite shall be high swelling, free flowing and have a particle size distribution favorable for uniform application and minimizing wind drift; (2) the application rate shall be at least 125 percent of the minimum rate found to be adequate in laboratory tests; (3) application rates recommended by a supplier shall be confirmed by an independent laboratory; (4) the water content of the soil-bentonite mixture shall be at or up to 4 percent above the optimum for maximum compaction; and (5) the coefficient of permeability shall not exceed the value derived in Section 94.22.

c. Specifications for construction and/or placement of a bentonite seal shall be based upon results of the preliminary testing program and at a minimum provide sealing of dikes prior to bottom, bentonite application procedures, seal density, covering of the seal and prehydration of the bentonite. Recommended requirements include: (1) bentonite shall be applied with specifically designed spreading equipment; (2) application shall be split such that one-half is applied in one direction and the remaining half in a perpendicular direction; (3) the bentonite shall be mixed into the soil to a uniform depth of at least three inches (7.5 centimeters); (4) the seal shall be compacted at the proper water content to at least 90 percent of Standard Proctor Density (specifically excluding use of a sheepsfoot roller); (5) the completed seal shall be covered with at least four inches (10 centimeters) of soil in addition to necessary erosion control as outlined in 94.17; and (6) the completed seal shall be hydrated with fresh water prior to introduction of wastewater and kept at or above the optimum water content until the pond is prefilled in accordance with Section 94.24.

d. The bentonite supplier or their representative shall verify that the specifications are in accordance with their recommendations, and written certification that the seal was provided and applied in accordance with specifications shall be furnished by the supplier, project engineer, or independent soils laboratory. The actual bentonite application rate and the water content and density shall be tested during seal construction. Permeability testing of undisturbed core samples shall be provided following seal completion. At least one test per acre (two tests per hectare) is required in all cases.

<u>94.223 Synthetic Liners</u> (Figure 6)

a. Requirements for thickness of synthetic seals may vary due to liner material but it is generally recommended that the linear thickness be no less than .020 inches or 20 "mil" (0.50 millimeters). Such thickness provides a safety factor

which will reduce the probability of puncture. Consideration should also be given to liners containing reinforcing in appropriate situations, such as sidewall slopes steeper than 3:1 or ponds depths greater than six feet (2 meters). Special care must be taken to select the appropriate material to perform under existing conditions.

b. Proper site preparation for synthetic liners is essential. The subsoil bed shall be sufficiently prepared to insure that all holes, rocks, stumps, and other debris are eliminated. The subsoil shall be sieved or the area raked after grading to provide a smooth, flat surface free of stones and other sharp protrusions which could damage the liner. If the subsoil contains sharp, non-removable objects, a bedding of two to four inches (5 - 10 centimeters) of clean soil or sand shall be provided.

Soil shall be well compacted and sterilized to kill vegetation. Four-inch (10-centimeter) perforated pipe should be strategically placed to allow venting and draining of the soil to reduce gas and hydrostatic pressures and to facilitate monitoring for leakage. The pipe should be installed in trenches sloping toward a sump and be backfilled with pea gravel or other coarse material.

c. Liner panels should be laid out in a longitudinal direction with an overlap of four to six inches (10 - 15 centimeters). Careful application of the appropriate adhesive is essential.

The anchor trench should have a minimum six-inch (15-centimeter) depth and be placed at least 9 - 12 inches (22 - 30 centimeters) beyond the slope break at the dike. Care must be exercised in the backfilling of the anchor trench to insure the liner is not damaged.

To prevent erosion, mechanical damage to the liner, and hydraulic lifting of the liner, a minimum backfill of six inches (15 centimeters) on the top of the liner is recommended. On the side slopes this should consist of a minimum three-inch (7.5 centimeter) primary fill of sand or finely textured soil and a minimum three-inch (7.5 centimeter) secondary fill of heavier cobble, coarse gravel or small riprap. On the bottom the backfill may consist solely of the sand or finely textured soils.

d. The manufacturer's representative shall supervise or conduct all phases of installation. It is also recommended that installation be done by contractors familiar with potential problems which can be encountered.

94.23 <u>Uniformity</u> The pond bottom shall be as level as possible at all points. Finished elevations shall not be more than one inch (2.5 centimeters) from the average elevation of the bottom. Shallow or feathering fringe areas usually result in locally unsatisfactory conditions.

94.24 <u>Prefilling</u> All ponds shall be prefilled to the two foot (0.6 meter) level to protect the liner, to prevent weed growth, to encourage rapid startup of the biological process and discourage odor, to reduce freeze up problems for late fall startups, to confirm the seal's integrity (as discussed in Section 94.22) and to maintain the water of the seal at or above optimum. However, the dikes must be completely prepared as described in Sections 94.171 and/or 94.172 before the introduction of water. Water for prefilling may be taken from the municipal water supply system or a nearby lake or stream. The raw sewage influent alone shall not be used for prefilling purposes.

APPENDIX C

TRADE NAMES AND SOURCES OF COMMON LINING MATERIALS (KAYS, 1977)[1]

Trade Name	Production Description	Manufacturer
Trade Names		
Aqua Sav	Butyl rubber	Plymouth Rubber Canton, Mass.
Armor last	Reinforced neoprene and Hypalon	Cooley, Inc. Pawtucket, R.I.
Armorshell	PVC-nylon laminates	Cooley, Inc. Pawtucket, R.I.
Armortite	PVC coated fabrics	Cooley, Inc. Pawtucket, R.I.
Arrowhead	Bentonite	Dresser Minerals Houston, Tex.
Biostate Liner	Biologically stable PVC	Goodyear Tire & Rubber Co. Akron, Ohio
Careymat	Prefabricated asphalt panels	Phillip Carey Co. Cincinnati, Ohio
CPE (resin)	Chlorinated PE resin	Dow Chemical Co. Midland, Mich.
Coverlight	Reinforced butyl and Hypalon	Reeves Brothers, Inc. New York, N.Y.
Driliner	Butyl rubber	Goodyear Tire & Rubber Co. Akron, Ohio
EPDM (resin)	Ethylene propylene diene monomer resins	U.S. Rubber Co. New York, N.Y.
Flexseal	Hypalon and Reinforced Hypalon	B. F. Goodrich Co. Akron, Ohio
Geon (resin)	PVC resin	B. F. Goodrich Co. Akron, Ohio
Griffolyn 45	Reinforced Hypalon	Griffolyn Co., Inc. Houston, Tex.
Griffolyn E	Reinforced PVC	Griffolyn Co., Inc. Houston, Tex.
Griffolyn V	Reinforced PVC, oil resistant	Griffolyn Co., Inc. Houston, Tex.

[1]Courtesy of John Wiley & Sons, Inc., New York, N.Y.

Trade Name	Production Description	Manufacturer
Hydroliner	Butyl rubber	Goodyear Tire & Rubber Co. Akron, Ohio
Hydromat	Prefabricated asphalt panels	W. R. Meadows, Inc. Elgin, Ill.
Hypalon (resin)	Chlorosulfonated PE resin	E. I. Du Pont Co. Wilmington, Del.
Ibex	Bentonite	Chas. Pfizer & Co. New York, N.Y.
Koroseal	PVC films	B. F. Goodrich Co. Akron, Ohio
Kreene	PVC films	Union Carbide & Chemical Co. New York, N.Y.
Meadowmat	Prefabricated asphalt panels with PVC Core	W. R. Meadows, Inc. Elgin, Ill.
National Baroid	Bentonite	National Lead Co. Houston, Tex.
Nordel (resin)	Ethylene propylene diene monomer resin	E. I. Du Pont Co. Wilmington, Del.
Panelcraft	Prefabricated asphalt panels	Envoy-APOC Long Beach, Calif.
Paraqual	EPDM and butyl	Aldan Rubber Co. Philadelphia, Pa.
Petromat	Polypropylene woven fabric (Base fabric-spray linings)	Phillips Petroleum Co. Bartlesville, Okla.
Pliobond	PVC adhesive	Goodyear Tire & Rubber Co. Akron, Ohio
Polyliner	PVC-CPE, alloy film	Goodyear Tire & Rubber Co. Akron, Ohio
Red Top	Bentonite	Wilbur Ellis Co. Fresno, Calif.
Royal Seal	EPDM and butyl	U.S. Rubber Co. Mishawaka, Ind.
SS-13	Waterborne dispersion	Lauratan Corp. Anaheim, Calif.

Trade Name	Production Description	Manufacturer
Sure Seal	Butyl, EPDM, neoprene, and Hypalon, plain and reinforced	Carlisle Corp. Carlisle, Pa.
Vinaliner	PVC	Goodyear Tire & Rubber Co. Akron, Ohio
Vinyl Clad	PVC, reinforced	Sun Chemical Co. Paterson, N.J.
Visqueen	PE resin	Ethyl Corp. Baton Rouge, La.
Volclay	Bentonite	American Colloid Co. Skokie, Ill.
Water Seal	Bentonite	Wyo-Ben Products Billings, Mont.

Materials	Manufacturers	Locations
Sources		
Bentonite	American Colloid Co.	Skokie, Ill.
	Archer-Daniels-Midland	Minneapolis, Minn.
	Ashland Chemical Co.	Cleveland, Ohio
	Chas. Pfizer & Co.	New York, N.Y.
	Dresser Minerals	Houston, Tex.
	National Lead Co.	Houston, Tex.
	Wilbur Ellis Co.	Fresno, Calif.
	Wyo-Ben Products, Inc.	Billings, Mont.
Butyl and EPDM	Carlisle Corp.	Carlisle, Pa.
	Goodyear Tire & Rubber Co.	Akron, Ohio
Butyl and EPDM, reinforced	Aldan Rubber Co.	Philadelphia, Pa.
	Carlisle Corp.	Carlisle, Pa.
	Plymouth Rubber Co.	Canton, Mass.
	Reeves Brothers, Inc.	New York, N.Y.
CPE, reinforced	Goodyear Tire & Rubber Co.	Akron, Ohio
Hypalon	Burke Rubber Co.	San Jose, Calif.
	B. F. Goodrich Co.	Akron, Ohio
Hypalon, reinforced	Burke Rubber Co.	San Jose, Calif.
	Carlisle Corp.	Carlisle, Pa.
	B. F. Goodrich Co.	Akron, Ohio
	Plymouth Rubber Co.	Canton, Mass.
	J. P. Stevens Co.	New York, N.Y.

Materials	Manufacturers	Locations
EPDM	See "Butyl and EPDM"	
EPDM, reinforced	See "Butyl and EPDM, reinforced"	
Neoprene	Carlisle Corp.	Carlisle, Pa.
	Firestone Tire & Rubber Co.	Akron, Ohio
	B. F. Goodrich Co.	Akron, Ohio
	Goodyear Tire & Rubber Co.	Akron, Ohio
Neoprene, reinforced	Carlisle Corp.	Carlisle, Pa.
	B. F. Goodrich Co.	Akron, Ohio
	Firestone Tire & Rubber Co.	Akron, Ohio
	Plymouth Rubber Co.	Canton, Mass.
	Reeves Brothers, Inc.	New York, N.Y.
PE	Monsanto Chemical Co.	St. Louis, Mo.
	Union Carbide, Inc.	New York, N.Y.
	Ethyl Corp.	Baton Rouge, La.
PE, reinforced	Griffolyn Co., Inc.	Houston, Tex.
PVC	Firestone Tire & Rubber Co.	Akron, Ohio
	B. F. Goodrich Co.	Akron, Ohio
	Goodyear Tire & Rubber Co.	Akron, Ohio
	Pantasote Co.	New York, N.Y.
	Stauffer Chemical Co.	New York, N.Y.
	Union Carbide, Inc.	New York, N.Y.
PVC, reinforced	Firestone Tire & Rubber Co.	Akron, Ohio
	B. F. Goodrich Co.	Akron, Ohio
	Goodyear Tire & Rubber Co.	Akron, Ohio
	Reeves Brothers, Inc.	New York, N.Y.
	Cooley, Inc.	Pawtucket, R.I.
	Sun Chemical Co.	Paterson, N.J.
Prefabricated asphalt panels	Envoy-APOC	Long Beach, Calif.
	Gulf Seal, Inc.	Houston, Tex.
	W. R. Meadows, Inc.	Elgin, Ill.
	Phillip Carey Co.	Cincinnati, Ohio
3110	E. I. Du Pont Co.	Louisville, Ky.

APPENDIX D

BENTONITE CLAY LININGS[1]

229-D

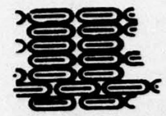
the VOLCLAY®

natural barrier phenomenon for seepage control and water impedance

- FRESHWATER LAGOONS
- MUNICIPAL WASTES OXIDATION LAGOONS
- HIGHLY CONTAMINATED INDUSTRIAL WASTES LAGOONS
- SANITARY LANDFILL LEACHATE SEEPAGE CONTROL
- TANK FARM OIL/ CHEMICAL SPILL SEEPAGE CONTROL

AMERICAN COLLOID COMPANY
INDUSTRIAL DIVISION
5100 SUFFIELD CT SKOKIE, IL 60076

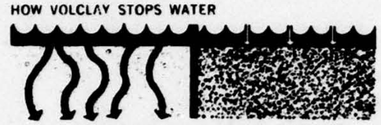
WHAT IS VOLCLAY?



Each platelet of Volclay surrounded by water. This "bound-water" forms a barrier against further water passage.

Volclay is a natural western bentonite clay product with the same chemical constituents as other clays, but with a unique molecular structure that permits it to absorb many times its weight in water. In doing so, Volclay swells enormously—up to 15 times its dry bulk when fully wetted. This wetting is reversible and Volclay can be dried and reswelled an infinite number of times.

HOW VOLCLAY STOPS WATER



Volclay's swelling and soil void jamming ability stops water passage. Without Volclay, the open voids let water flow through the soil.

Volclay's thirst for water and swelling are its strengths in stopping the passage of water. Under confined conditions, as in a buried mixed blanket, the wetted, swelled Volclay particles will be jammed against each other and into voids between soil particles to form a barrier against further passage of water and fluids. Kept wet Volclay never sets or hardens, and maintains its "water-bound" condition forever.

FLEXIBILITY WITHSTANDS GROUND MOVEMENT

Volclay's unusual flexibility stems from the "bound-water" condition that permits the movement of bentonite particles without breaking the water barrier seal. Ground movements that would rupture other liners normally have no affect on a Volclay barrier.

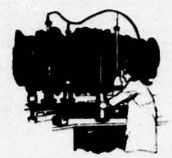
SELF-SEALING ABILITY

In extreme cases where severe ground movement would rupture the seal or a foreign object would penetrate it, Volclay particles will migrate with the seepage flow to affect a resealing action.

PERMANENCY

Volclay's water impeding ability is permanent and will not degrade as long as it has been properly hydrated with fresh water to activate the swelling process.

THE VOLCLAY SOIL ANALYSIS LABORATORY IS AT YOUR SERVICE



Test column being set up to establish permeability rate of soil sample mixed with Volclay Saline Seal 100.

Conductivity test being conducted on soil samples to establish its suitability for use in a mixed blanket.

Among the advantages of specifying Volclay products is the technical assistance you get in determining correct grade selection and application rate. The Volclay soil analysis laboratory is at your service at all times.

Technicians under the direction of a registered professional engineer will provide soil testing expertise. They use procedures which are acceptable by engineers and governmental agencies throughout the United States.

Samples sent in for analysis should be taken from several locations, especially if a large lagoon is being planned or if there is a question about the soil being uniform. To test soil for a contaminated industrial wastes lagoon, a sample of the liquid to be stored should be used.

VOLCLAY EASILY APPLIED

Easy application is a prime factor for selecting Volclay soil sealants. In most cases the mixed blanket method of spreading, disking and compacting is preferred. In certain cases a protective cover should be used to avoid puncturing the sealing blanket. Where water or wastes are already in a pond and it can not be drained, the sprinkle or slurry placement method must be used. In most instances, factory or field reps will be of assistance.

229-D © American Colloid Company 9/75

AMERICAN COLLOID COMPANY, INDUSTRIAL DIVISION
5100 Suffield Court, Skokie, Ill., 60076
Phone (312) 966-5720 Telex 724-413
Cable-Volclay TWX910-223-0738

VOLCLAY SALES REPRESENTATIVE

[1]Courtesy of American Colloid Company, Skokie, Illinois.

VOLCLAY Soil Sealants

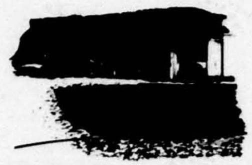
FRESHWAT[illegible] LAGOONS

Volclay Bentonite blanket forms a water retaining barrier

Volclay soil sealants make it practical to construct freshwater lagoons and lakes in almost any type of soil and in any configuration. Being a natural material, the Volclay bentonite can in no way pollute the stored water and surrounding environment.

SG-40 or any other Volclay grade specified, with the help of our soil analysis, will form a water tight lagoon bottom barrier that will last indefinitely. The unusual flexibility of this material helps it withstand quite strong ground shifts. In many areas, where water is both costly and scarce, Volclay's positive sealing ability is very important. Low in initial cost, this material is usually applied inexpensively, as a mixed blanket between 2 and 4 inches thick.

HIGH[illegible] CONTAMINAT[illegible] INDUSTRIA[illegible] AGOONS



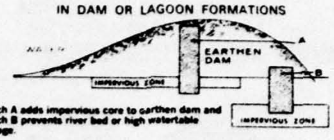
Volclay sealed highly contaminated wastes lagoon at chemical processing plant.

Volclay Saline Seal 100, a protected, high swelling bentonite is especially formulated to withstand highly contaminated wastes. The high ionic salt level usually found in certain industrial wastes will not affect the swelling ability of Saline Seal 100. In tests and actual application there has been no evidence of any soil sealant failure regardless of the type or degree of contamination.

Saline Seal 100 can be applied either as a mixed blanket, in the normal manner, or when dry application is impossible, as a slurry on wet or unstable soils. The only specific requirement for Saline Seal 100 application is complete freshwater hydration before introduction of contaminated wastes.

SLURR[illegible] [illegible] CONSTR[illegible]

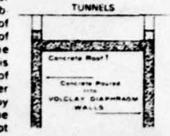
IN DAM OR LAGOON FORMATIONS



Trench A adds impervious core to earthen dam and Trench B prevents river bed or high watertable seepage.

Volclay Ultra Gel 180 bentonite is an extremely efficient material for slurry trenching. The bentonite absorbs water and each platelet of clay surrounds itself with a jacket of water thus giving Volclay the ability to develope viscosity. This viscosity permits the stabilization of excavations and the flow of water through trench walls is stopped by Volclay's soil sealing ability. Fine solids such as sand and silt are kept in suspension for eventual displacement along with the slurry when concrete or other fill is placed in trench.

TUNNELS



Poured concrete in Volclay diaphragm walls with concrete roof in excavated area.

MUNICIPAL WASTES OXIDATION LAGOONS

Six soil municipal wastes oxidation lagoon with Volclay sealed bottom has been in service over 12 years.

Volclay Soil Sealants have become the key ingredient in the building of many municipal waste oxidation lagoons. Hundreds of these lagoons have been operating satisfactorily for years in smaller and medium sized communities. The cost of building a well designed lagoon is usually less than that of an equivalent capacity mechanical plant.

Volclay Soil Sealants are inexpensive and the soil analysis and field advice assures, proper grade selection and correct application for long life.

Unusual flexibility to withstand lagoon bottom shifts can mean extremely low maintenance costs. Small leaks are self-mending and larger repairs can be easily made without draining and shutdown.

MUNICIPAL AND INDUSTRIAL LANDFILL LEACHATE SEEPAGE CONTROL

Volclay barrier and "umbrella" for the control of landfill leachate seepage.

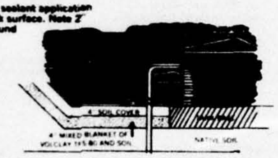
Volclay SLS Soil Sealant system provides a positive, low cost way to control leachate seepage in municipal and industrial sanitary landfills. SLS is a protected, contaminant resistant bentonite similar to Saline Seal 100 that will withstand prolonged contact with highly contaminated leachate.

Easily applied to the bottom and sides of landfills in a mixed blanket, Volclay SLS provides a low cost, permanent barrier to prevent groundwater contamination. In unusual situations a slurry wall of SLS keyed into the impermeable zone, will help control excessive leachate runoff.

Once a landfill is completed an "umbrella" cover of Volclay SG-40 is placed in a mixed blanket over the entire site. This controls infiltration of water from rain and melting snow thus preventing additional leachate formation.

TANK FARM SEEPAGE PROTECTION FROM OIL AND CHEMICAL SPI[illegible]

Volclay TFS-80 soil sealant application with protective work surface. Note 2" bead of TFS-80 around pipes and other protrusions.

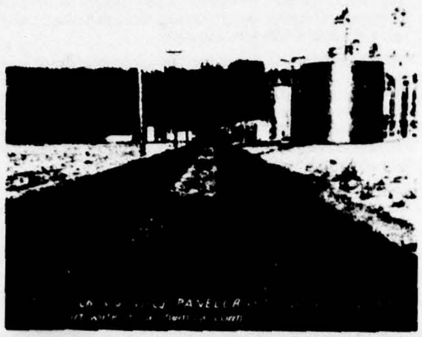


Today, spills and leakage in tank farm areas are extremely serious because of the possible seepage of pollutants into groundwater supplies. Volclay TFS-80, a newly developed, protected bentonite Tank Farm soil sealant can now be used to prevent this type of seepage. Once activated with fresh water, it is totally unaffected by any of the oils and chemicals usually stored in tank farms.

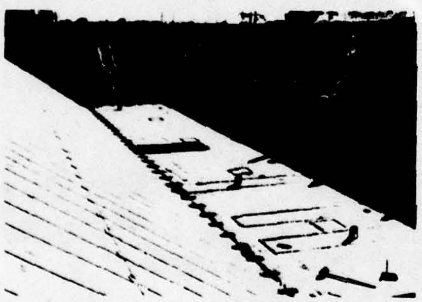
Applied as a mixed blanket inside the dike area, and up the dike slope, the Volclay mixture is then covered with about 4" of soil to provide an insulating, protective work surface. Due to earth shifts that generally occur because of tank loading and unloading, the flexible nature of Volclay TFS-80 is important in providing rupture free, long life protection.

APPENDIX E

ASPHALT PANEL LININGS[1]

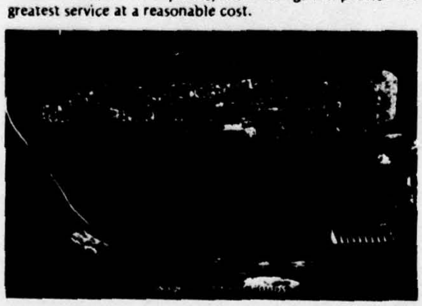


PANELCRAFT panels can be installed around equipment foundations. The panels are unaffected by fluid motion of domestic sewage and other water-based fluids in properly designed reservoirs and storage systems with agitation systems.



Flexibility to move with Earth Movements

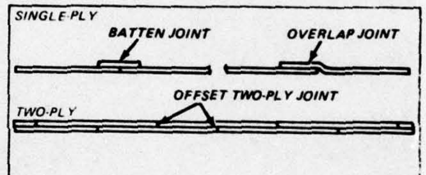
PANELCRAFT panels are used in many multi-acre reservoirs of great depth and similar facilities in areas of HIGH-SEISMIC activity. With reasonable care and planning during installation, facilitated and made possible by the flexibility of the *PANELCRAFT* panels, these linings will provide the greatest service at a reasonable cost.



Single-ply and Two-ply options

PANELCRAFT linings may be installed in either of two ways, depending upon the type of reservoir, pond, or other storage system:

- The single-thickness (1/2-inch) system of installation can be either installed with edges butted together and a batten strip placed over the butt point, or the panels can be overlapped to obtain the desired joint.
- For those applications requiring a perfectly smooth surface (for sweeping and other cleaning requirements, for example), the use of two layers of 1/4-inch *PANELCRAFT* panels is recommended. The first layer of panels are installed, with ends butted together, and the second layer is placed on top of the first, with the second layer of panels offset approximately one-half panel to prevent butt joints from being directly over each other.



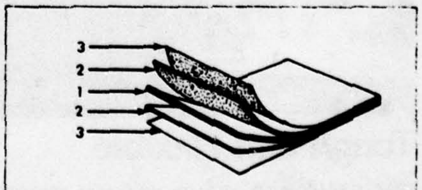
PANEL INSTALLATION

Either of the above installation systems provide maximum protection from water loss, and may be walked on, swept, and subjected to normal earth movement without loss of protection. *PANELCRAFT* system requires no additional protective coverings.

PANELCRAFT linings are made of high-grade bitumen, reinforced with *FIBERGLASS*. This construction makes possible an odorless liner that imparts no taste to the water, and that is strong and flexible.

As shown in the cutaway drawing, the panels are made in five layers:

1. The core of ductile air-blown asphalt, fortified with minerals and reinforcing fibers, thoroughly compounded and molded under pressure and heat into panels of desired thickness and length.
2. Coverings of flexible *FIBERGLASS MAT* on both sides of the core.
3. Protective coating of water repelling asphalt, hot applied to both sides of panel.



PANEL CONSTRUCTION

PANELCRAFT fits properly compacted ground contours perfectly, and adjusts quickly to normal earth movements. No heaving, distorting, or damage from hot or cold weather.

[1] Courtesy of Asphalt Products Oil Corp., Long Beach, California.

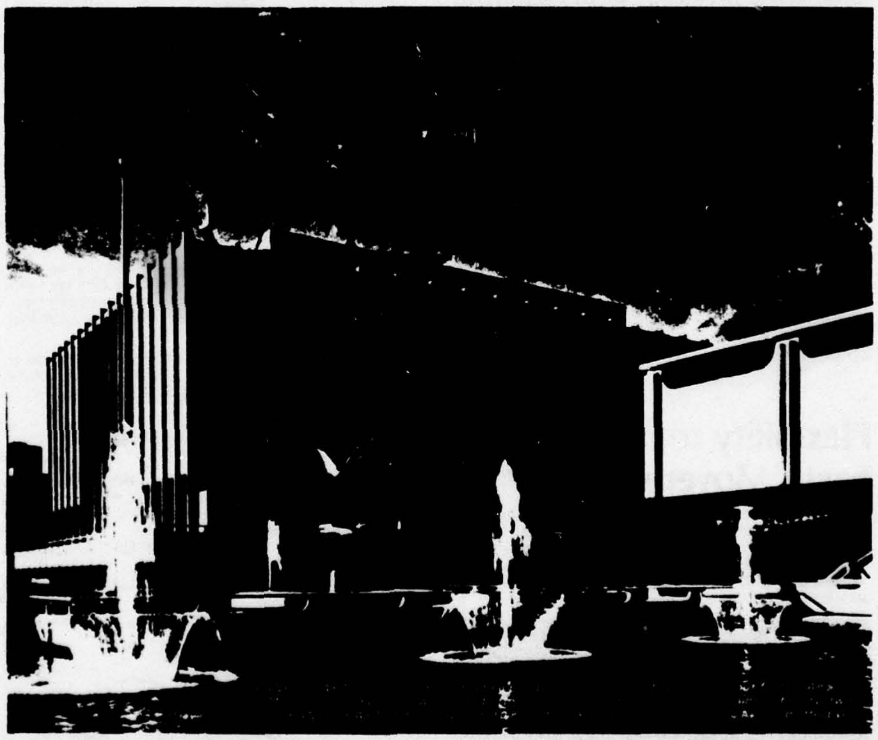
Protecting our Water Resources

PANELCRAFT linings are protecting reservoirs, lakes, canals, reflecting ponds, holding basins, sewage ponds and other water conservation and storage systems from loss of water through leakage, seepage, and intrusion – *SUCCESSFULLY FOR OVER TWO DECADES.*

The need for protection and conservation of our precious water supplies is obvious. The large population movement to arid areas, the normal population growth, the expansion of water-oriented residential and retirement areas, recreation areas, and urban and suburban greenbelts places enormous demands on our relatively finite water resources. Maximum use must be obtained from every drop of water – for its beauty of appearance, for its life-support properties in drinking water, and its utility in the production of food, manufacture, and even disposal. Every plan that includes water *MUST BE WATERPROOF.* Every drop of water must be protected against waste and loss through leakage, seepage, and contamination by intrusion.

PANELCRAFT will insure the leakage protection of your reservoir, lake, canal, or other storage system – and will provide this protection economically with long life, durability, and minimum maintenance. Some storage systems using *PANELCRAFT* are over 20 years old – and now *PANELCRAFT* is ***FIBERGLASS REINFORCED*** for strength, stability, and flexibility.

Today's ecological planning often requires the storage of brine and other water-based byproducts in storage basins to prevent their intrusion into the soil and local water table. *PANELCRAFT* provides complete strength and leakproof capabilities to such holding basins. The flexibility of *PANELCRAFT* insures that this integrity is maintained even when subjected to the motion and disruption of filling and emptying for distribution to disposal points.



Tough and Flexible

PANELCRAFT linings are tough and flexible, providing protection from penetration during normal access and maintenance tasks, and the flexibility insures that the panels will not crack under the normal movements of the earth and pressures and forces that result from water flow, addition, and drainage. *PANELCRAFT* panels have come to the rescue of cracked and leaking concrete and other rigid material construction reservoirs and storage systems. *PANELCRAFT* is simply installed over the otherwise troubled concrete system, placing the reservoir or storage system back into operation in the shortest time possible.

APPENDIX F

HYPALON LINERS[1]

INSTALLATION PROCEDURE FOR

BURKE HYPALON 45 POND/PIT LINERS

[1]Courtesy of Burke Rubber Company, Burke Industries, San Jose, California.

TABLE OF CONTENTS

INSTALLATION PLAN

General Sequence of Events

1. Make ready all materials required for installation prior to commencement of lining operations. See attached check-off list of materials.

2. Unroll and unfold only those panels which are to be anchored or seamed together in one day. See attached procedure for unrolling and unfolding techniques.

3. After the panels are initially placed, it is desirable to remove as many wrinkles as possible. The purpose of this is to make the edges to be bonded as smooth and free of wrinkles as possible.

4. As soon as the panels are in position, commence field-seaming operations. See attached procedure on field seaming techniques.

5. At the end of each day all unseamed edges shall be anchored by sandbags. If winds are expected, the use of boards along the edges of the panels, with sandbags on top, should be used to anchor liner.

6. After field-seaming is complete in a given area, liner edges in anchor trench should be buried.

   NOTE: Do not bury the liner edge in the anchor trench within 30 feet of an "incomplete" field seam. This is to allow the seam area to be retensioned to remove wrinkles along the seam area.

7. In selecting the sequence to be used in field-seaming, always start in the middle and work toward an open end. This will minimize large wrinkles from becoming trapped, which requires cutting and patching.

Customer should supply the listed materials
for installation of prefabricated panels of
BURKE HYPALON LINERS

---

1. All field installation labor and official supervision, i.e., crew chief or foreman.

2. Means to move rolled-up panels of pond liner to specified locations at pit site. Rolls 4' diameter by 7' long will weigh approximately 2,500 to 5,000 lbs.

3. Stakes and string or chalk lines (not lime) to define panels locations and initial unroll guidelines as indicated on the marked-up print provided.

4. Canvas, burlap, or polyethylene bags filled with sand or soft dirt to hold the unseamed edges in place; quantity depends on wind present during installation; figure on one bag per five to ten feet of unanchored panel perimeter.

5. Five to ten hand rakes, or large paving rakes.

6. One or more small compacting roller for smoothing out or compacting rough or badly gouged earth at the pit site (such as a lawn roller).

7. Portable hot air gun. (See seaming tool list).

8. Five to ten shovels.

9. Large box or barrel of clean cotton rags.

10. Tape measure, 100-foot.

11. Roll of twine or heavy string.

12. Old boards, such as 1" x 4", 2" x 4", 1" x 6", 1" x 8" for holding unseamed edges in place while awaiting seaming (to be used in conjunction with above sandbags).

13. A way to drag a 2,500-5,000 lb. strip of folded pond liner if required--rope, pipe and pulling means.

14. All proper safety equipment and supplies. Responsibility for all safety aspects of the installation is the customer's.

15. All persons at the site to have smooth, protrusion-free shoe soles and heels. (Tennis shoes).

16. A 10-foot plus length of 2-1/2" to 4" pipe.

17. Two 8-foot lengths of wood, 2" x 4".

18. Fifty feet of 1/2", 5/8", or 3/4" rope.

19. Wooden dowels, 3/4" to 1-1/2" diameter, approximately 12" long. Ends to be rounded smooth. These dowels used to facilitate crew in holding onto liner as it unfolds.

20. If field seaming will be performed, all required equipment per the attached "tool list for field-seaming crew" should be provided.

CUSTOMER MAKE-READY LIST

Things to be accomplished the afternoon or evening before commencement of the lining operations.

1. All equipment, tools and supplies to be at the pond site in a suitable storage area.

2. The first day's panels to be in position as shown on the layout drawing. Leave the panels packaged, and if hot sunlight is present, shade the panels from direct sunlight using any opaque sheeting; leave free-flowing air space between opaque sheeting and panels.

3. Anchor trench dug all around pond. Excavated anchor trench dirt to be spread out (raked back, flat, away from anchor trench) so that panels can be unrolled on the top of the berm.

4. Stakes and/or lines indicating panel locations as shown on the layout drawing to be installed.

5. All pond dimensions to be checked to verify that actual pond dimensions are not greater than those dimensions shown on the drawing.

6. Pond to be ready to be covered with liner.

   A. Pond surface raked, smooth, rolled if necessary; free of all large, sharp rocks or other sharp objects, free of all vegetation and vegetation stubble.

   B. All penetrations, (pipes, etc.) covered or wrapped to protect liner from being cut, abraded or punctured during installation.

   C. All concrete slabs and skirts around penetrating pipes swept clean and free of all debris and rocks. Where subsequent bonding to concrete is to be done, the surface to be smooth, clean, dry and ready for adhesive applications.

   D. All pipes, drains, fittings, etc., which are to be installed beneath the liner should be in place ready to be covered with liner.

7. Distribute sandbags (about one every five feet) along the perimeters of the area to be lined the next day. Don't put them in the area where the panels will be unrolled, but immediately adjacent thereto.

General Instructions for Unrolling
and Unfolding Prefabricated Panels of
BURKE HYPALON LINERS

1. The package is marked on the outside clearly indicating the panel identification letter and the directions for unrolling and unfolding. When locating the packaged panels, observe these markings so panels can be unrolled and unfolded in the proper direction. (It is also clearly marked on the roll of material inside).

2. Leave packaging on the panel until ready to unroll. If the panel will be sitting in direct sunlight for over 1/2 hour before unrolling, it should be completely shaded with any opaque sheeting. It is necessary to leave a free-flowing air space between the opaque sheeting and the packaged panel.

3. When ready to unroll the panels, remove the packaging carefully DO NOT USE A KNIFE AS DAMAGE TO LINER MAY OCCUR. Before unrolling off of the pallet, carefully inspect the pallet for and remove any protrusions which may damage the liner.

4. The panel is normally unrolled by inserting a 2-1/2" to 4" diameter pipe 10-12' long, through the cardboard core and then looping a rope over each of the projecting ends of the pipe. The rope should be out close to the ends of the pipe and away from the roll of Hypalon sheeting. The rope should not touch the Hypalon during unrolling. By putting an equal number of men on each rope and pulling, the panel is unrolled along the desired guide line. Crew size: One man/1,000 sq. ft. of any one panel (e.g., 15,000 sq. ft. panel requires 15 men).

5. After the panel is unrolled, it is straightened out to the guide line as indicated by the technical advisor or crew chief.

6. The panel is then unfolded into position. Men are positioned at the edge of the panel as indicated by the technical advisor or crew chief. Generally, the men are positioned approximately 15 feet apart, depending on the size of the panel and the terrain to be covered. If required, men are positioned at the uphill end of the panel to keep it from sliding down the slope as it is unfolded. If the edge to be gripped is subsequently to be bonded, then the panel edge is folded back about two or three feet, and the fold is gripped for pulling rather than the edge. This is to avoid stretching the edge where it is to be bonded. Gripping of the panel can be facilitated by use of a short length of wood dowel, 3/4" to 1-1/2" in diameter, and 12" to 18" long. The liner is first wrapped around the dowel, and then gripped. The edges of the dowels should be carefully rounded off to prevent sharp edges from digging into the liner as it is pulled.

7. As the panel is pulled out it is necessary to maintain air under the liner. This air can be obtained and maintained by several means. One way to maintain air under the liner is to simply hold the edge up and advance at a rate fast enough to capture air under the liner as it is unfolded. Another way is the same as above, except the edge is constantly raised and lowered as it is being spread out to "fan" air under the liner.

When there is a prevailing wind from the direction to which the liner is being pulled, then air can be introduced by lifting the edge just enough to allow the described amount of air to blow in under the liner. Care must be exercised in this case to only raise the edge of the liner enough to let the "desired" amount of air under the liner and lower to cut off the air as soon as enough air is captured; otherwise, it is possible to have the liner blow away.

When the panel has been partially spread and it is necessary to stop (as is often the case) the edge should be lowered to try to trap as much air as possible and keep it from escaping. In spite of this, some air will escape and it is necessary to introduce more air under the liner; this is accomplished by "fanning" the edge of the sheet up and down, and sending waves of air far in under the panel. A common mistake is, when attempting to do this, the crew does not get enough vertical height on the fanning action; the edge of the liner should be raised from over-the-head level down to knee level as the cyclic fanning action is performed. This fanning action should be continued as directed by the technical advisor or crew chief before spreading of the liner is attempted.

8. A slight lateral tension on the leading edge of the panel being spread should be maintained. This lateral tension facilitates the spreading operations.

9. NOTES:

A. Generally, a 2:1 slope is the steepest slope which men can walk on to spread the liner. Where the liner must be installed on a slope steeper than 2:1, special detailed plans must be worked out ahead of time by the people responsible for planning the job.

B. During unfolding-spreading operations it is necessary that the crew wear work gloves, as these operations can be quite chafing to the knuckles.

C. During unfolding-spreading operations it is necessary that the crew work as a team. The technical advisor shall provide instructions which will facilitate this requirement.

D. If a gust of wind attempts to pull the liner away from the crew and they are about to lose their footing, the following points are applicable:

1. Put lateral tension in the leading edge and lower it to the ground.

2. Attempt to restrain it further by putting one knee on the leading edge.

If these efforts fail to restrain it, LET IT GO. DO NOT HOLD ONTO THE LINER AND BE PULLED ALONG WITH THE WIND.

E. It is advisable that all persons at the pond site wear soft rubber-soled shoes such as tennis shoes or boat shoes.

F. Extreme caution should be exercised when walking on the Hypalon liner material when it is wet. The sheeting becomes very slippery. It is generally necessary to use a rope as an aid in going in or out of the pond.

RECOMMENDED GUIDELINES

1. Under ideal soil and weather conditions, removal of surface cure should not be completed more than ten minutes ahead of seaming. Under adverse conditions such as high heat, winds, muddy substrate or other conditions which increase the possibility of foreign material to be deposited on the washed surfaces, the amount of time between washing and seaming should be reduced at the discretion of the technical advisor or crew chief.

2. Before adhesive is applied, surfaces to be seamed must have surface cure thoroughly removed and be essentially free of dirt and foreign materials. The presence of a few particles of sand or dirt is permissible in situations where such presence is unavoidable. The acceptable limit for such presence is where the few particles are totally encapsulated in the adhesive/seam and they do not connect to form a path for a leak.

3. On hot days, better results in removal of surface cure may be achieved by the use of perchloroethylene.

4. "Fishmouths" can be folded over and bonded closed or slit, bonded down, and patched per instructions given by the technical advisor. Patches over fishmouths or other seam flaws should extend at least 2" past the flaw in question. The rule on patches should be, "if there is any question as to whether to patch or not, then patch it!"

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WASTEWATER STABILIZATION POND LININGS.(U)
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Field Seaming Procedure for
BURKE HYPALON LINER MATERIAL

MANDATORY PROVISIONS

Overlaps

Minimum overlap - 4".

Seams

Minimum seam width - 2".

Preparation

A. Remove all foreign matter, loose dirt, oil, etc., from edges to be bonded together.

B. Surfaces to be seamed must be washed with rags or natural bristle scrub brushes soaked with trichloroethylene or perchloroethylene to remove surface cure. Surface cure is removed when Hypalon turns shiny and slick when wet and a dull black when dry.

Application of Adhesive

Apply a liberal amount of Hypalon adhesive to one of the surfaces and lap together immediately--no delay between the time the adhesive is applied and material overlapped. Adhesive must be thoroughly wet at the time surfaces are joined, with no evidence of surface "skinning" or drying of the adhesive.

Seaming Method

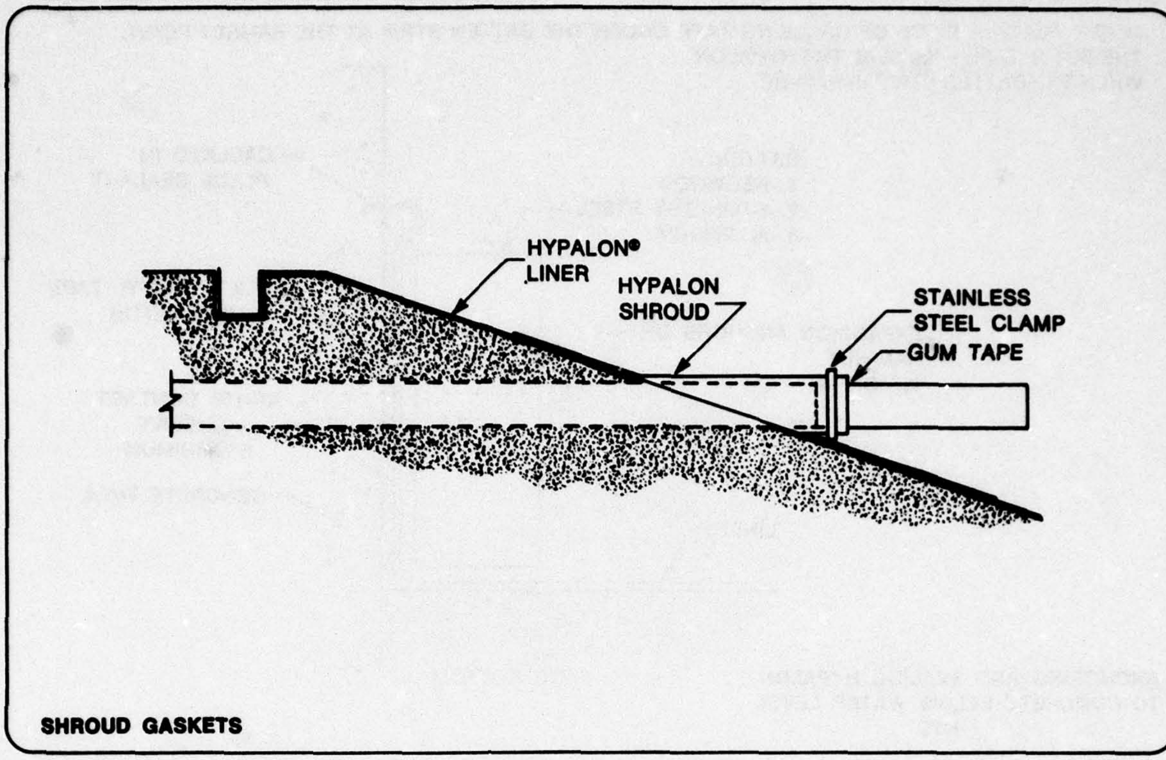
Seam is "stitched" by rolling with a steel roller in a direction perpendicular to the seam, applying firm pressure. A small amount of adhesive, forced out of the seam edge, is desirable and indicates sufficient adhesive has been applied.

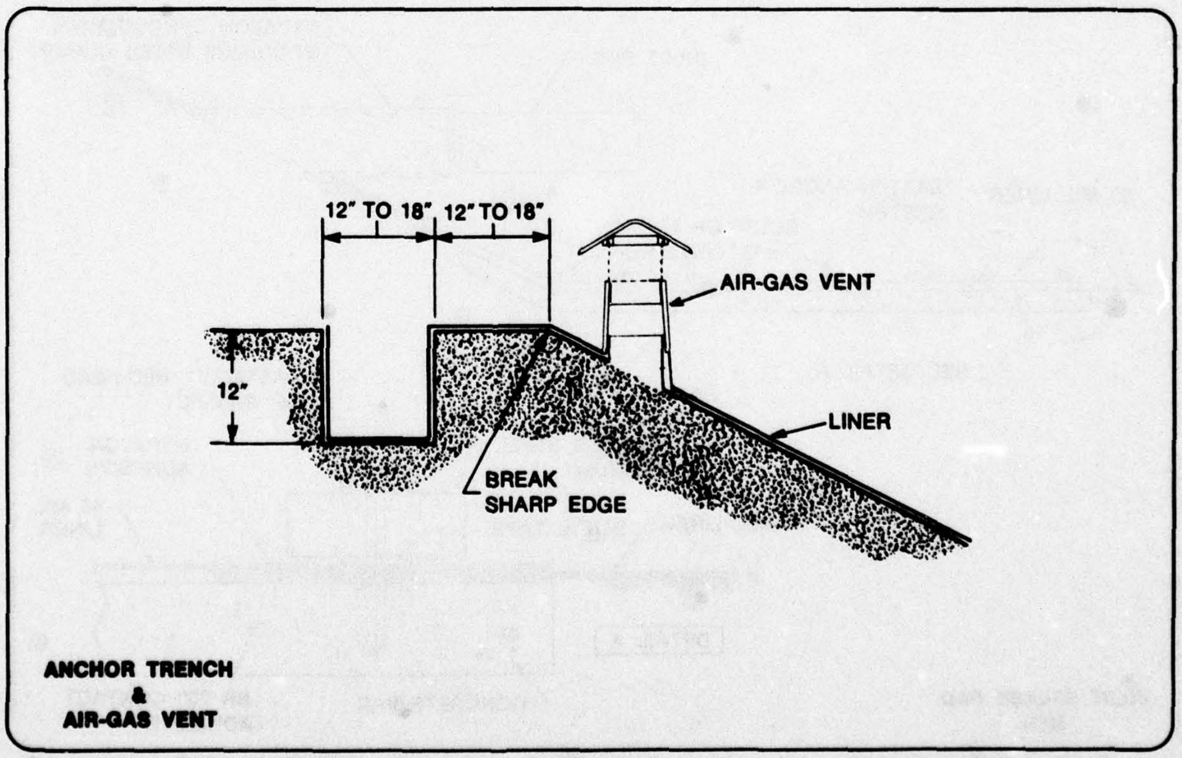
NOTE: The temperature of the sheet and adhesive when bonding must be above 60° F. minimum. If ambient conditions create temperatures lower than this, then the sheet and adhesive must be warmed by artificial means; i.e., hot air guns, radiant heaters, heat lamps, spare heaters, etc.

TOOL LIST

For Field Seaming Crews

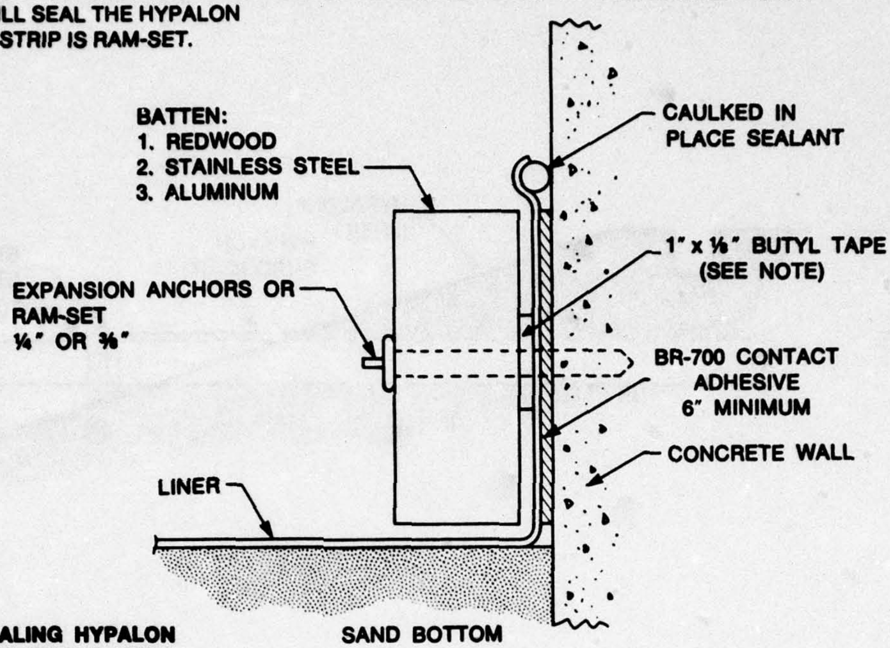
1. Each man on the seaming crew to wear PVA (polyvinyl alcohol) coated gloves. Edmont-Wilson, Coshocton, Ohio 43812. Their No. 37-165, or equal.
2. Three sets, Size 10, cloth gloves.
3. Two sets knee pads. (If desired).
4. Roll of tape to hold on knee pads.
5. Gallon can with handle, with trichloroethylene. (Consumption rate same as adhesive).
6. Ten cotton rags per hour.
7. Gallon can with handle, with adhesive.
8. A 3" paint roller with bent wire handle.
9. A 12" to 18" long length of 1/2" to 3/4" diameter metal tubing (will be used to make handle for paint roller).
10. A 2" diameter x 2" long, flat-face, steel roller with handle ("stitcher"). Hoggson brand, from H. M. Royal, Inc., 11911 Woodruff Avenue, Downey, CA. Telephone 213-773-3774.
11. A stiff bristle, natural bristle scrub brush.
12. A whisk broom (or fox tail brush).
13. A 1" x 10" x 10' long Douglas fir, clear board, rounded off on both ends and rounded off on all edges with a rope tied to one end.
14. A Stanley knife.
15. One red or yellow crayon for marking liner surface.
16. A pair of scissors with rounded-off points.
17. Each man on seaming crew safety glasses (for protection from solvent splash).



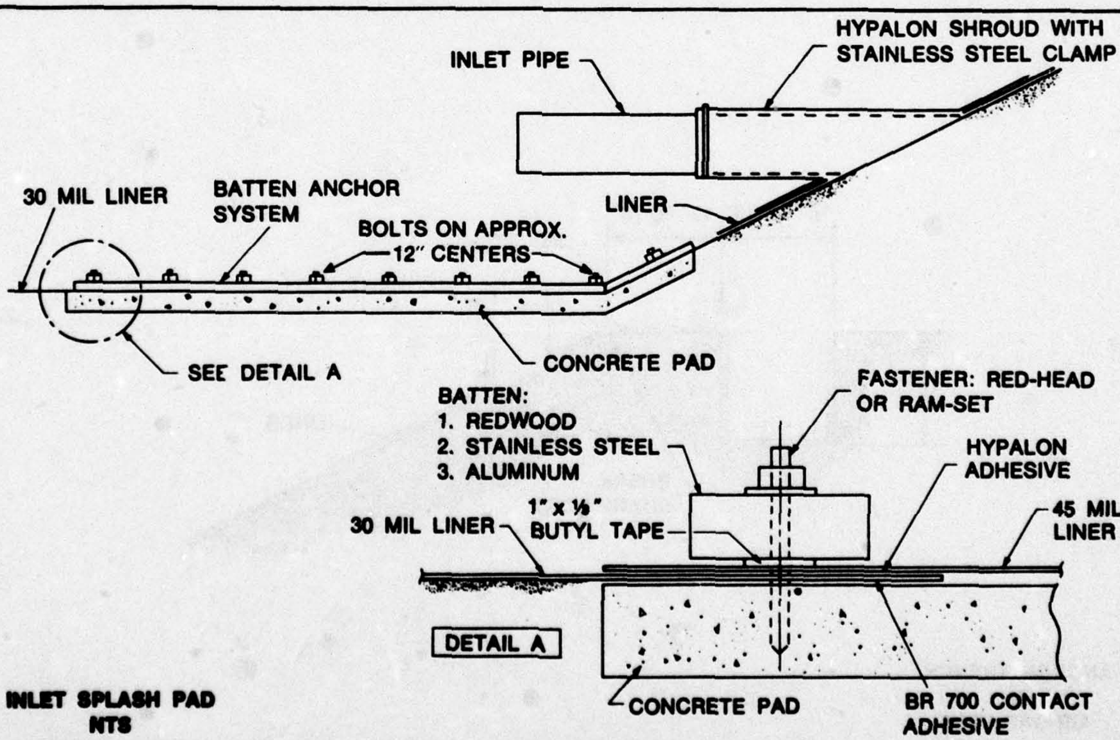


Courtesy of Burke Rubber Company, Burke Industries, San Jose, California

NOTE: PLACE A PIECE OF CAULKING TAPE UNDER THE BATTEN STRIP AT THE RAMSET POINT. THE BUTYL TAPE WILL SEAL THE HYPALON WHEN THE BATTEN STRIP IS RAM-SET.



ANCHORING AND SEALING HYPALON TO CONCRETE BELOW WATER LEVEL
NTS



INLET SPLASH PAD
NTS

Courtesy of Burke Rubber Company, Burke Industries, San Jose, California

APPENDIX G
B.F. GOODRICH "FLEXSEAL" LINEARS

INFORMATION BULLETIN

B.F.GOODRICH GENERAL PRODUCTS COMPANY

EL-1.6-176

D/0414, WHB-3 — 500 South Main Street   Akron, Ohio 44318

INSTALLATION GUIDE FOR B.F.GOODRICH POND LINERS

I. General

B.F.Goodrich Pond Liners are all purpose, tough, durable, rubber or PVC linings that are heat welded into large panels up to 15,000 square feet each. These in turn can be easily assembled, as described later, for lining all possible sized pits, ponds, reservoirs, canals and lagoons.

II. Tools and Equipment Required for Installation

Listed below are the materials and equipment that are typically required on job site before installation can be accomplished. Please have the materials indicated before the day of installation.

1. A means of handling large rolls of material: Forklift, Front end Loader, Crane, or Boom truck.
2. ________ 4" paint brushes.
3. ________ 2" wide hand rollers (Steel or Nylon).
4. ________ 16' or 20', 1" x 10" clear white pine board or conveyor belt.
5. ________ 50 pound sand bags or tire carcasses.
6. ________ pounds of clean rags.
7. ________ 1 quart caulking gun.
8. ________ 1 gallon paint pails for solvent.
9. ________ 6 feet - 2" steel heavy wall (schedule 80) pipe.
10. ________ 10 foot chains.
11. 1 ea. 1" x 2" x 12" wooden sticks per man.

Lists: O-GP, 1-SP-E, 1-SP-W

Courtesy of B.F. Goodrich, Akron, Ohio.

III. Receiving and Storage of Lining Material

Material is shipped in rolls up to 6 feet diameter, 5 feet long, strapped on skids or in pallet boxes. Depending upon the size of the panels, they can weight up to 4,000 pounds each. The liner is typically packed in a white covering to reflect the sun's heat and can usually be stored outside at the site for one to three weeks before starting the installation with no harm to the material. If the job is delayed for an extended time (more than three weeks), material must be stored inside or in open shade. PVC Liners should be stored at temperatures not lower than 50°F.

IV. Preparing the Site for the Installation of the Liner

Pond should be free of all standing water or mud. Entire surface to be lined must be free from all rock, roots, and debris that may puncture the liner material.

Anchor trench should be dug as per drawings and material properly spotted for installation.

The area to be lined should have the soil sterilized. This is especially true of areas having prior growths of nut or quack grasses.

V. Equipment Needed for Spotting the Material

The panels will weigh up to 4,000 pounds. A large front end loader, bulldozer or crane is required to spot the rolls of material.

Material is accordion folded in the length direction, then rolled in the width direction. The package is marked in the direction the material must be unrolled and pulled into the pond so that the correct side is up and placed in its proper position without extra handling. The roll is normally spotted at one corner of the final resting place of the panel, either along the berm or on a large installation, in the bottom of the pond.

VI. Positioning the Panels for Seaming

Unroll the material using a 6'-2" diameter heavy walled pipe through the core of the roll chained to the truck or front end loader, being certain to unroll material so that the end of the material will be in the proper position when unfolded.

With small 1" x 2" x 12" sticks in hand, line 10 or 12 men along the 50' folded material. With each man grasping the top layer of material and rolling the stick into the material 4" to 8", the material is ready to be pulled into the pond.

After the material is 75 to 100 feet into the pond, place a man on each side of the panel and have them flip air under the panel. The cushion of air underneath the material makes moving a panel 300 feet long relatively easy.

When the first panel is in position, temporarily anchor it in the berm trench with sandbags leaving the edges free to be seamed. The edge of the panel that will be seamed to the next panel should be re-positioned so that it is as straight and lying as smooth as possible. Then back fill trench partially to hold panel in place.

Position the next panel in the same manner and allow a 6" overlap of material into the first panel. After panel is in position, weight panel edges with sand bags or old tire carcasses. Be certain to position panel so that the edges to be seamed lie straight and as smooth as possible before attempting any seaming.

VII. Adhesive Seaming of Flexseal-Hypalon Pond Liners

Both liner surfaces of the overlap must be free of dirt or mud. If not, wash with water and dry. Wash both surfaces with cleaning solvent using neoprene gloves for hand protection.

Starting at the center of two panels to be seamed, place a 1" x 10" x 16' board or conveyor belting underneath the overlapped area. With adhesive, mark outside of the overlap. Fold overlap back and apply an even coat of adhesive 4" wide to both surfaces. Be careful not to allow coating surfaces to come in contact with each other before properly positioned. Adhesive surfaces are ready to be placed together when the wettest area will not transfer to your clean knuckle when pressed onto the adhesive surface.

Carefully apply the two surfaces together avoiding any wrinkles or folds. Using a 2" hand roller, overlapped area with firm pressure to insure a 100% bond. Pay particular attention to any area that consists of more than one layer of material (overlapped cross seams).

After overlap is completed upon the length of the board, apply a coat of adhesive to the 3" tape and an area 3" wide centered on the edge of the overlap just made.

Allow adhesive to dry, using the knuckle test to tell when adhesive is dry enough to position tape over the seam edge. Position tape and roll firmly with a hand roller.

Pull board or belting from underneath this section and proceed with the next section. Two crews may now start seaming toward each end of the panel.

Notes of *caution*:

1. Apply even coats of adhesive.

2. Allow to dry to the touch.

3. Avoid wrinkles.

4. Use a hand roller with firm pressure.

5. Use a board or belting as a working surface.

VIII. Proceed with the next panels in the same manner. Do not lay more material than can be sealed in one day.

IX. Inlet and Outlet Pipes that Penetrate the Liner.

We recommended all penetrations through the liner and attachments to the liner be in accordance with B.F.Goodrich Information Bulletin EL-1.5-775.

INFORMATION BULLETIN

B.F. GOODRICH GENERAL PRODUCTS COMPANY

P. O. Box 657 Marietta, Ohio 45750

BULLETIN
EL-1.5-775

Typical Installation Details for B.F.Goodrich Flexseal® Pond and Pit Liners

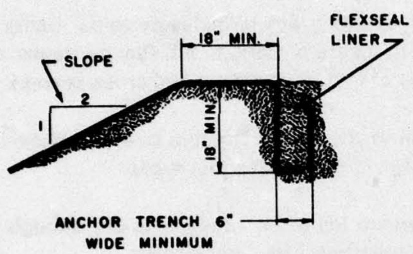


Figure #1

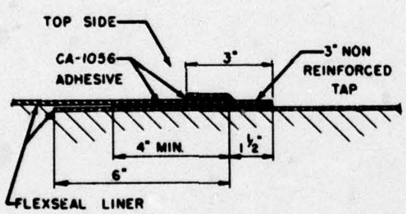


Figure #2

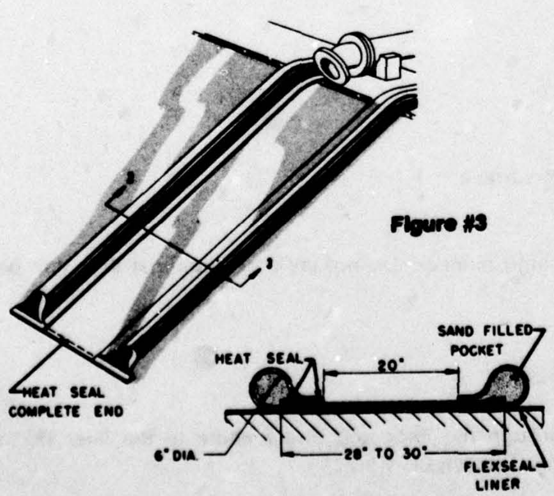


Figure #3

Figure #1

The anchor trench should be located far enough from the edge of the berm to provide a sufficient anchor for the liner, as well as enough room to use a ditcher to dig the trench. The dirt thrown towards the lagoon may be raked back into the ditch, provided a minimum 18" depth is maintained.

Figure #2

The field seam illustrated is used for the reinforced Flexseal material. The 3" wide non-reinforced tape prevents wicking of the effluent into the reinforcing fabric. If non-reinforced Flexseal liner material is specified and used, the 3" tape is not normally required.

Figure #3

As illustrated, the easiest method of placing inlet and outlet pipes into Flexseal lined lagoon is over the top of the berms, using a protective liner to contain the discharge, thus protecting the main liner. The fewer protrusions that are designed into a lining, the easier it is to install and maintain both the liner and the piping.

A double layer of liner material over the liner at the inlet may also be sufficient, as opposed to the prefabricated trough illustrated.

Flexseal Lining — Penetration Attachments
— Flange Type Method —

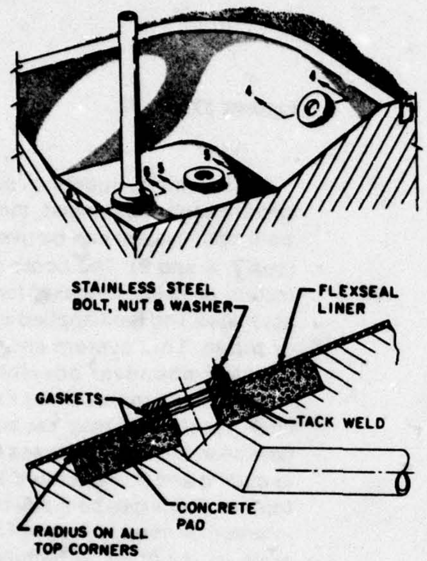


Figure #4

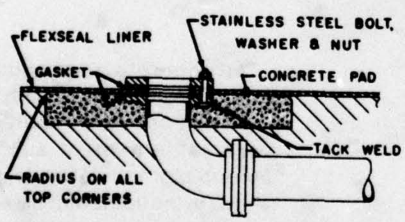


Figure #5

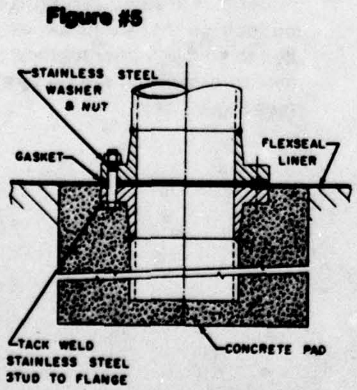


Figure #6

Figures #4, #5, #6

If an inlet or outlet pipe or support post must penetrate the Flexseal liner, B.F.Goodrich recommends a flanged system be used.

As illustrated in Figures 4, 5 and 6, all attachment points have a good mechanical seal to the penetrating pipes. The concrete pads around the pipes should be used to prevent ground settlement and undue stress to the lining material. This system also allows the installation of large panels without cutting and fitting around the protrusion.

All corners of the concrete pads should be rounded and have a smooth troweled surface to prevent unnecessary wear points. The use of a flanged extension pipe may be used to divert the effluent away from the liner if necessary.

At an outlet pipe, 100# sacks of concrete should be placed around the outlet five feet apart approximately ten feet from the pipe. This is to prevent the liner from being sucked into the outlet pipe.

Flexseal Lining Penetration Attachments
— Boot Type Method —

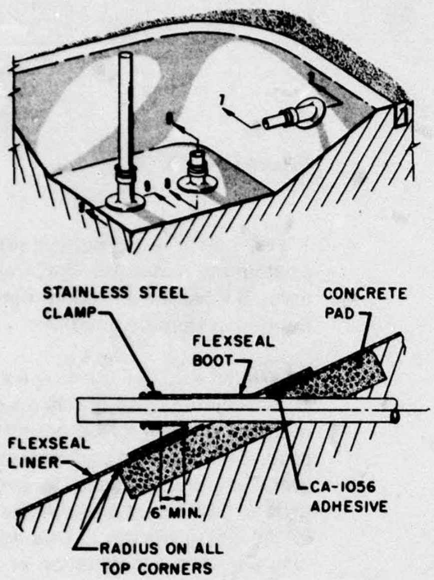


Figure #7

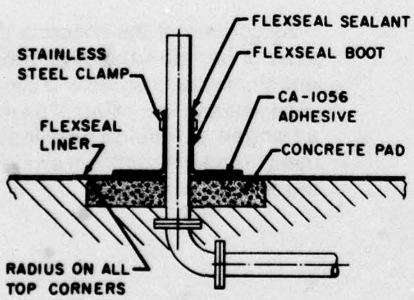


Figure #8

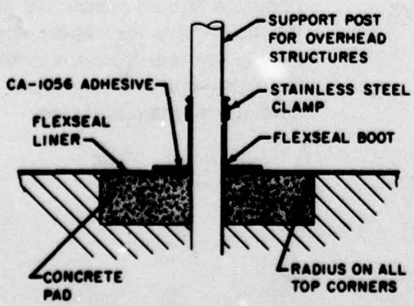


Figure #9

Figures #7, #8, #9

Where inlets, outlets or support pipes cannot be flanged, the alternate boot system can be used (figures 7, 8 and 9). The boots can be factory or field fabricated for small pipe sizes and field applied on larger pipes. This system should be avoided whenever possible. It is more difficult to install the Flexseal liner panels and may cause more field seaming than is necessary due to cutting and fitting around the protrusion. Boots can be made from reinforced or non-reinforced Flexseal material. All pipes to be flashed in this manner should be smooth and clean. Clamping straps should be of material that will not be attacked by the effluent.

All concrete pads should have round edges and smooth surface. Concrete pads are required to prevent settlement of sub-surface around pipes, thus reducing undue stress to the boots and Flexseal liner material. Large culvert type inlet or outlet pipe that would be very difficult to seal by either method can be sealed directly to the concrete pad (see Figure 14).

Flexseal Lining
Ventilation and Underdrain System

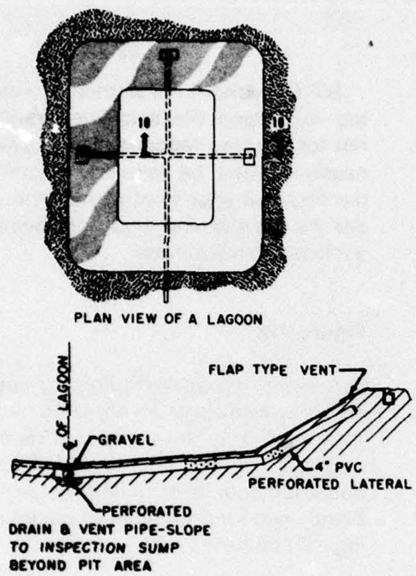


Figure #10

Figure #10

B.F.Goodrich recommends a venting and underdrain system on most installations. Gases caused by a fluctuating water table pumping air under the liner or from decaying organics will be trapped under the Flexseal liner causing it to float unless some precautions are taken. If the smallest bottom dimension is larger than 25 feet and less than 50 feet, a simple center drain or vent may be used. If the smallest dimension is greater than 50 feet, a lateral system should be considered. The laterals should be placed approximately 50 feet on centers. The center drain or vent system, if run to a sump, may also act as a leak detection system.

The lateral vents should run up the slope to within a foot of the top and screened off to keep out surrounding dirt and gravel.

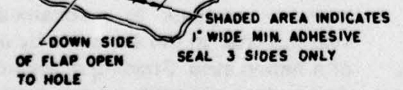


Figure #11

Figure #11

Directly above the end of the lateral a flap type vent should be placed in the liner to allow venting through the liner.

Flap type vents are also recommended on any lagoon where a free board of liner material is more than 4 or 5 feet. This helps relieve pressure under the liner if wind causes the Flexseal liner to lift off the berm.

Flexseal Lining
of
Aerated Lagoons and Concrete Attachments

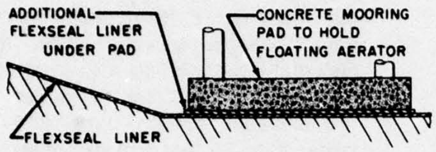


Figure #12

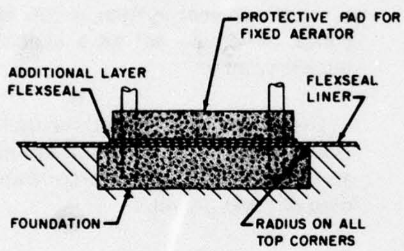


Figure #13

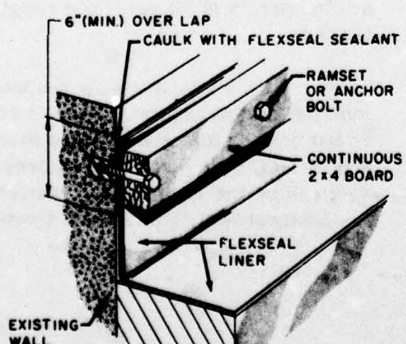


Figure #14

B.F.Goodrich recommends using reinforced Flexseal liner material for aerated lagoons. Some precautions must be taken to protect the Flexseal liner from abrasion under the aerator and also from being sucked into the aerator.

Figure #12

A mooring pad for a floating aerator may also act as an abrasion pad. This pad may be poured directly over the Flexseal liner with at least one additional layer of liner material being used for protection when pouring the concrete.

Figure #13

On fixed aerators the liner material may be anchored to the pad or totally cover the pad, then an additional layer of concrete poured on top of the pad to protect the liner and/or anchorage of the liner. 100# sacks of concrete used as weights should be placed ten feet apart, approximately twenty feet from aerator base. This is to insure the liner is not sucked into the aerator.

Figure #14

Anchoring Flexseal liner to existing or new concrete pads, walls or weirs may be accomplished by using anchor bolts, cast in place or drilled later, or ramsets to mechanically seal the liner to the concrete by use of a batten strip. Spacing of anchors depends on rigidity of the batten strip.

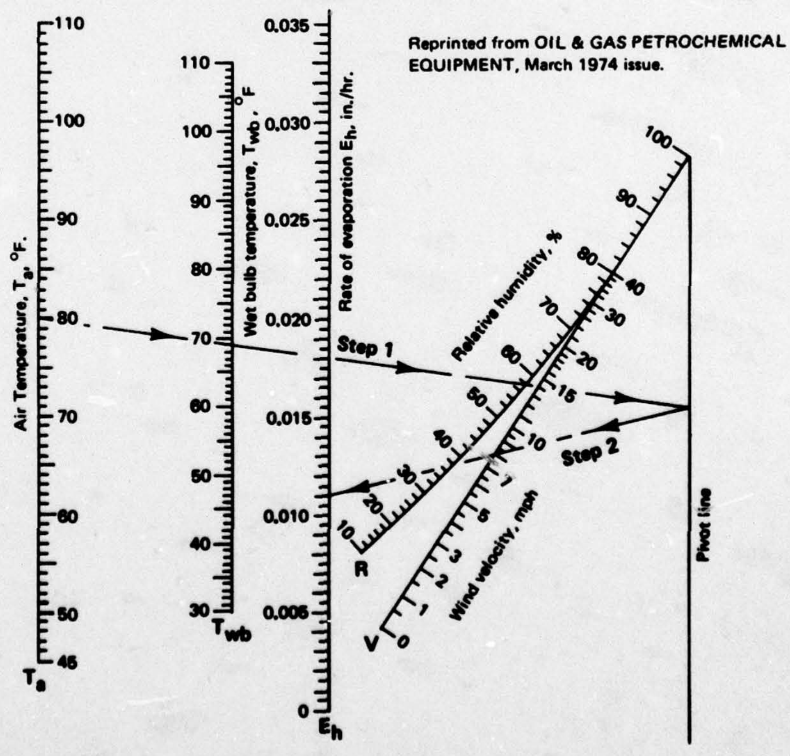
Evaporation Nomograph

DATA on evaporation from lakes and reservoirs are not extensive. But there are formulas by which it may be computed. One of these; by Fitzgerald, has the form, $E_h = (S\text{-}F)\ (1 + v/2)/60$; where E_h = evaporation rate, in./hr; S = vapor pressure of water at water temperature, in. Hg; F = vapor pressure existing in the air; and v = wind velocity, mph. Wind velocities are at the water surface and may be taken at one-half those recorded at an elevated station such as the Weather Bureau stations. For larger reservoirs, however, Weather Bureau values give results in close agreement with available direct measurements.

An alternative and substantially equivalent formula is given by Fitzgerald in more usable terms. Somewhat simplified and transformed; it is: $E_h = 0.0002\ (T_a - T_{wb})\ (1 + v/2)$; where T_a and T_{wb} are in the air temperature and wet-bulb temperature, respectively. The nomogram is based on the second formula. It includes the relative humidity for convenience.

Example. Assume the "normal" or long-term monthly temperature, relative humidity, and wind velocity for a certain location are 80°F., 58%, and 8 mph; what is the "normal" wet-bulb temperature, and what is the evaporation rate per hour and per month of 31 days?

Solution. Step 1, line 80°F, on T_a scale with 58% on R scale, extend to Pivot line and mark. Also read wet-bulb temperature as 69°F. where line crossed T_{wb} scale. Step 2, from marked position Pivot line, connect with 8 mph on V scale, extend to E_h scale, and read evaporation rate as 0.011 in./hr. The evaporation rate per month = 0.011 X 24 X 31 = 8.184 in.



Reprinted from OIL & GAS PETROCHEMICAL EQUIPMENT, March 1974 issue.

APPENDIX H

POLYVINYL CHLORIDE LINERS[1]

WATERSAVER COMPANY, INC.

3560 WYNKOOP STREET • DENVER, COLORADO 80216 • (303) 623-4111

Data Sheet SPVC - 74

STANDARD SPECIFICATIONS

POLYVINYL CHLORIDE PLASTIC LININGS

01 - GENERAL REQUIREMENTS

The work covered by these specifications consists of installing a polyvinyl chloride (PVC) plastic lining in the (lagoon, reservoir, canal, etc.) where shown on the drawings or directed by the Engineer. All work shall be done in strict accordance with the drawings and these specifications and subject to the terms and conditions of the contract.

02 - PVC MATERIALS

A. General. The materials supplied under these specifications shall be first quality products designed and manufactured specifically for the purposes of this work, and which have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes.

B. Description of PVC Materials. PVC (polyvinyl chloride) plastic lining shall consist of widths of calendered polyvinyl chloride sheeting fabricated into large sections by means of special factory-bonded seams into a single panel, or into the minimum number of large panels required to fit the jobsite as supplied by WATERSAVER CO., INC., 3560 Wynkoop St., Denver, Colorado.

1. Physical Characteristics. The PVC materials shall have the following physical characteristics.

TEST	TYPICAL TEST VALUES	TEST METHOD
Specific Gravity	1.24 - 1.30	ASTM D792-66
Tensile Strength, psi, min.	2200	ASTM D882-B
Elongation, % min.	300 %	ASTM D882-B
100% Modulus, psi.	1000 - 1600	ASTM D882-B
Elmendorfer Tear, gms/mil, min.	160	ASTM 689
Graves Tear, lbs./in. min.	270	ASTM D1004
Water Extraction, % max.	0.35	ASTM D1239
Volatility, % max.	0.7	ASTM D1203
Impact Cold Crack, °F.	-20	ASTM 1790
Dimensional Stability, max.%		
100°C. - 15 minutes	5	
Shore Durometer, "A"	65--70	ASTM D676
Outdoor Exposure, sun hrs.	1500	
Bonded Seam Strength, % of Tensile, min	80 %	
Pinholes/10 Sq. Yds. max	1	Meets USBR Test specially formulated for resistance to micro biological attack. Passes Corps of Eng. CRD572-61.
Color	Black	

[1] Courtesy of Watersaver Company, Inc., Denver, Colorado.

2. PVC materials shall be manufactured from domestic virgin polyvinyl chloride resin and specifically compounded for the use in hydraulic facilities. Reprocessed material shall not be used. It shall be neutral gray to black in color and produced in a standard minimum width of at least 54 inches. Thickness shall be as shown on the drawings. Certification test results showing that the sheeting meets the specifications shall be supplied on request.

03 - FACTORY FABRICATION

Individual widths of PVC materials shall be fabricated into large sections by dielectric sealing into a single piece, or into a minimum number of panels, up to 100 feet wide, as required to fit the facility. Lap joints with a minimum joint width of 1/2 inch shall be used. After fabrication, the lining shall be accordion folded in both directions and packaged for minimum handling in the field. Shipping boxes shall be substantial enough to prevent damage to contents.

04 - PLACING OF PVC LINING

A. General. The PVC lining shall be placed over the prepared surfaces to be lined in such a manner as to assure minimum handling. It shall be sealed to all concrete structures and other openings through the lining in accordance with details shown on the drawings submitted by the contractor and approved by the Engineer. The lining shall be closely fitted and sealed around inlets, outlets and other projections through the lining. Any portion of lining damaged during installation shall be removed or repaired by using an additional piece of lining as specified hereinafter.

1. Field Joints. Lap joints will be used to seal factory fabricated panels of PVC together in the field. Lap joints shall be formed by lapping the edges of panels a minimum of 2 inches. The contact surfaces of the panels shall be wiped clean to remove all dirt, dust or other foreign materials. Sufficient cold-applied vinyl to vinyl bonding adhesive shall be applied to the contact surfaces in the joint area, and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

2. Joints to Structures. All curing compounds and coatings shall be completely removed from the joint area. Joining of PVC to concrete shall be made with vinyl to concrete adhesive. Unless otherwise shown on the drawings, the minimum width of concrete shelf provided for the cemented joint shall be 8 inches.

3. Repairs to PVC. Any necessary repairs to the PVC shall be patched with the lining material itself and cold applied vinyl to vinyl bonding adhesive. The bonding adhesive shall be applied to the contact surfaces of both the patch and lining to be repaired, and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

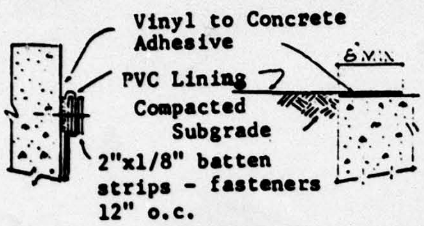
4. Quality of Workmanship. All joints, on completion of the work, shall be tightly bonded. Any lining surface showing injury due to scuffing, penetration by foreign objects or distress from rough subgrade shall, as directed by the Engineer, be replaced or covered and sealed with an additional layer of PVC of the proper size.

A Technical Service Representative will be made available to the contractor if the contractor desires. The contractor will bear the expense of this Technical Service Representative. The Technical Service Representative is not directly responsible for the quality of the work involved; such responsibility will be solely that of the contractor.

WATERSAVER COMPANY, INC.

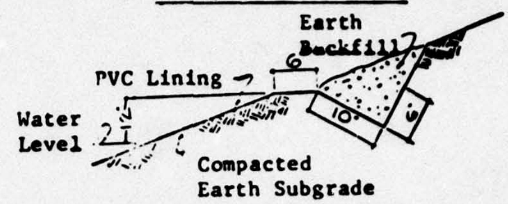
3560 WYNKOOP STREET • DENVER, COLORADO 80216 • (303) 623-4111

DATA SHEET DET - 74

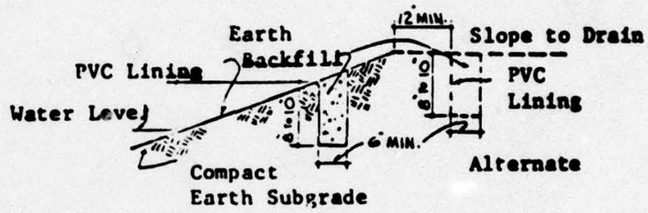


ANCHOR TO CONCRETE STRUCTURES

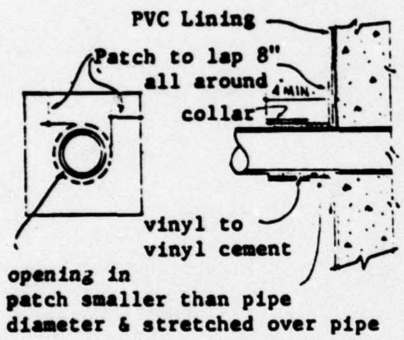
ANCHOR - METHOD #1



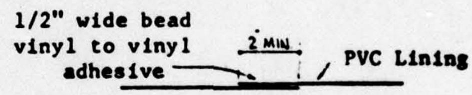
ANCHOR - METHOD #2



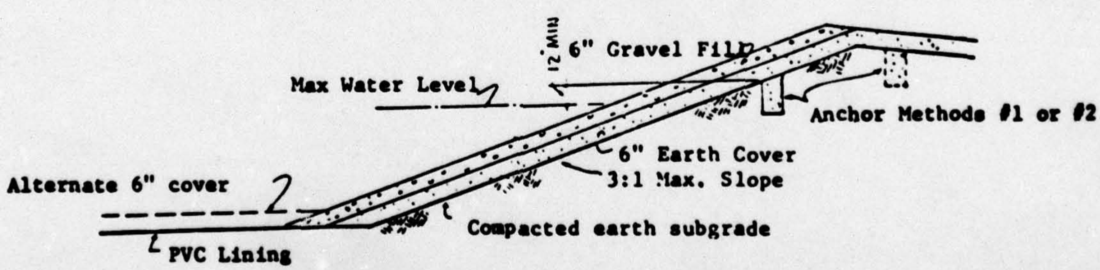
TOP OF SLOPE ANCHORAGE



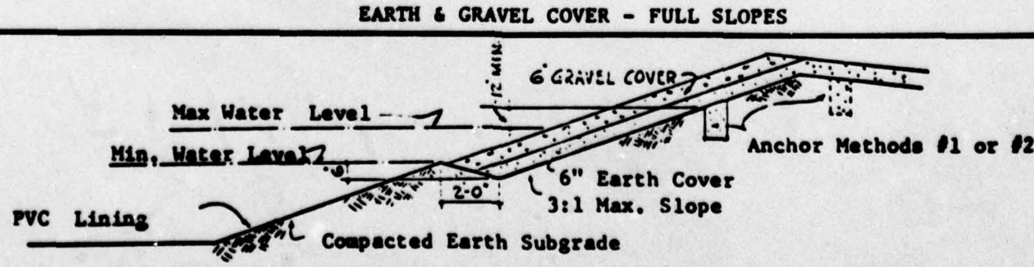
SEAL TO PIPE



TYPICAL LAP SPLICE JOINT



EARTH & GRAVEL COVER - FULL SLOPES



EARTH & GRAVEL COVER - PARTIAL SLOPES

APPENDIX I

VARIOUS LINER MATERIALS[1]

STAFF INDUSTRIES, INC.

78 Dryden Road, Upper Montclair, N.J. 07043 201-744-5367
240 Chene Street, Detroit, Michigan 48207 313-259-1820

GENERAL INSTRUCTIONS FOR INSTALLATION of STAFF LINERS FOR PREVENTING SEEPAGE from PONDS, RESERVOIRS, CANALS, LAGOONS, etc.

Staff seepage prevention liners are made from tough, impermeable elastomeric sheeting, both reinforced and unreinforced specially compounded for long life when properly installed. Liner sections are fabricated up to widths of 70½ feet by lengths up to weights of two tons, in various gauges. Bonding solvent is supplied for joining sections in the field where it is necessary to cover wider areas.

We recommend that all liners for ponds, reservoirs, lagoons, etc., be covered with earth for mechanical protection from animals, men, and weather. However, where necessary, and when they can be properly protected, lining materials with superior outdoor durability may be used as exposed membranes.

Staff Industries fabricates large liners for use in structures designed and constructed by others. The following shall serve as guidelines for the use of Staff seepage prevention liners.

1. SITE PREPARATION

The liner sections as supplied by Staff Industries are impermeable to water and gas. (For special instructions regarding high water table and gassy areas, see #2, below.) All sharp sticks, stones, and trash should be removed from the bottoms and sides of the installation, or covered with fine soil. Areas containing nut grass and quack grass should be sterilized. Preferably, the area to be covered should be rolled to effect compaction and smoothing so as to reduce local stresses on the membrane. At all times care should be taken to prevent puncturing of the liner during installation and use. A perimeter trench 8 to 12 inches square, above the waterline, is generally used for anchoring the membrane. (See sketches on reverse side.)

2. HIGH WATER TABLE AND GASSY AREAS

If liners are installed over decomposing materials such as organic wastes, bogs, etc., or in areas of fluctuating water tables which "pump" air, bubbles can develop and come to the surface. They will be unable to escape because of the impermeability of the lining to water and gas and the fact that, under water, the liner has very little weight. Where such conditions might exist, special precautions should be incorporated in the design to allow venting of such gas to the sides by sloping bottoms and a layer of gas-permeable soils directly under the liner. Also, it is strongly recommended that the liner be covered on the bottom to provide weight to aid in gas removal, in addition to other possible venting methods.

3. INSTALLATION OF LINERS

Staff liners are shipped accordion-folded in both directions for easy opening, first in the length direction and then in the width direction. Various methods of installing liners have been used, and one of them will now be described: A boxed section designed for a certain area in the installation is placed on the back of a truck, front-end loader, or other carrier, with the box length crosswise, and taken to the area where it is to be installed. After the steel straps are cut, the box top and sides can be removed vertically, leaving the accordion-folded liner on a pallet, from which it can be opened lengthwise by holding the end and driving the vehicle forward while unfolding the liner. The first section is generally positioned on the berm so that one edge can be buried in the anchor trench, before the rest is opened down the slope. The second section is then positioned adjacent to the first section and unfolded so that the two can be joined, as described below, to cover the total areas required.

For joining two sections together, a long smooth work surface is recommended. A 1" x 10" x 20' board is particularly suitable and can be used directly on dry ground, or on supports above wet ground. The two liner edges to be joined are overlapped 2 to 4 inches along the center line of the board and aligned by two workmen, who also clean the area of any dust, dirt, or moisture, using a rag or brush. The sheeting must be perfectly dry before the bonding solvent is applied. The two men then slightly tension the area, while a third man injects the bonding solvent between the two positioned films (at the rate of about 1 ounce per 30 feet), using the squeeze bottles which are supplied for this purpose. It is not necessary or desirable to turn back the top edge of the sheeting. Slight hand pressure with a rag should be applied immediately after the bonding solvent is injected. If any edges remain unsealed, the bonding application can be repeated so as to bond the flap completely. The board is then moved forward for sealing the next area. (Sometimes a rope is attached to the forward end of the board for pulling it ahead.)

After the seam is completed, the bonding solvent will have bonded the sections sufficiently so that the newly added section can be opened to its full width and another section positioned and bonded. Shear strength develops in 5 to 15 minutes, but peel strength requires several days for solvent dissipation. Seams should be carefully inspected, after a half hour or more, to detect and reseal any voids in the seam.

4. OBSTRUCTION SEALING

For sealing around connections, walkways, etc., several methods can be used. For round connections, a hole ½ the diameter of the connection is made in the film, and this hole is then stretched over the connection, (which has been coated with a special adhesive for bonding sheeting to steel and to clean concrete), producing an upturned collar. This collar is then reinforced with a strip of film and some of the special adhesive. In the case of connections of square or other shapes, the film can be adhered with the adhesive. It is also possible to fabricate from film and the bonding agent specially shaped collars, attach them to the connection, and then adhere the liner to the collars. Around walkways or docks it will be necessary to cut the film and glue it to fit as well as possible, and then make and adhere collars to the posts and film so as to seal the connections watertight.

5. COVERING OF LINERS

To prevent damage to the sheeting, it is recommended that all lining surfaces be covered with earth, if possible. For side slopes, free-draining earth should be topped with erosion-resistant material such as gravel. In order to retain soil and gravel cover on the sides, a slope not steeper than 3:1 is necessary. (Concrete can be used to cover steeper slopes.) Covering of heavier membranes which will not be subject to mechanical damage and vandalism can be by water only, if desired and gas development under the lining will not take place. A water layer will prevent damaging effects of heat to the liner as well as provide protection. Some facilities which are expected to be maintained almost constantly full of water have been designed with a bench below the waterline. Cover is then maintained above the bench, but no cover except water would be used below the bench. (See last two sketches on reverse side.) Equipment used in covering the sides and bottoms of lined structures can be clamshells, front-end loaders, bulldozers, dump trucks, elevating graders, carryalls, graders, etc. Though liners are tough, equipment should not be driven directly on them, unless it is tested and proved on the job site that damage will not result. Even then, careful supervision should be provided.

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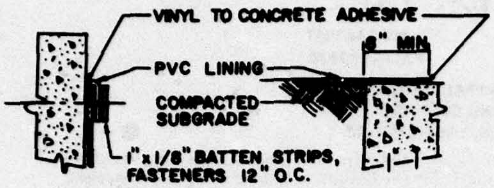
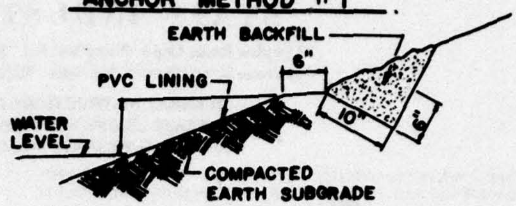
[1] Courtesy of Staff Industries, Inc., Upper Montclair, N.J., and Detroit, Michigan.

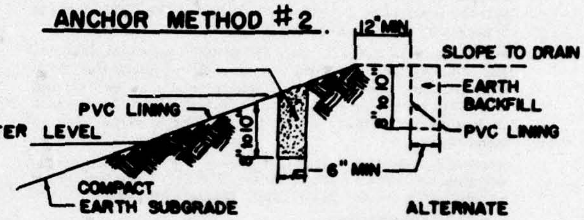


ANCHOR TO CONCRETE STRUCTURES

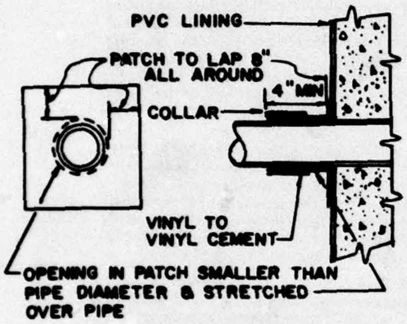
ANCHOR METHOD #1



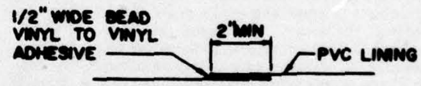
ANCHOR METHOD #2



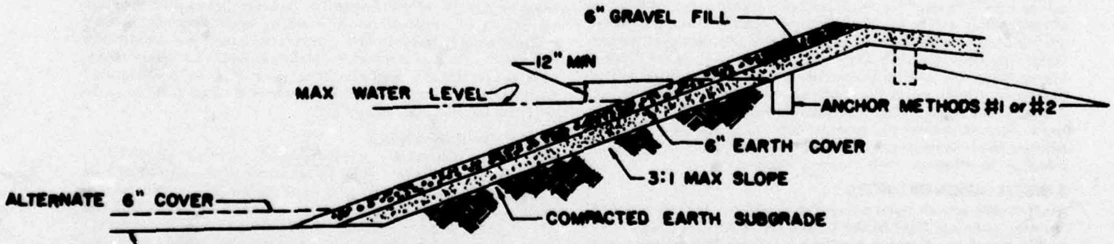
TOP OF SLOPE ANCHORAGE



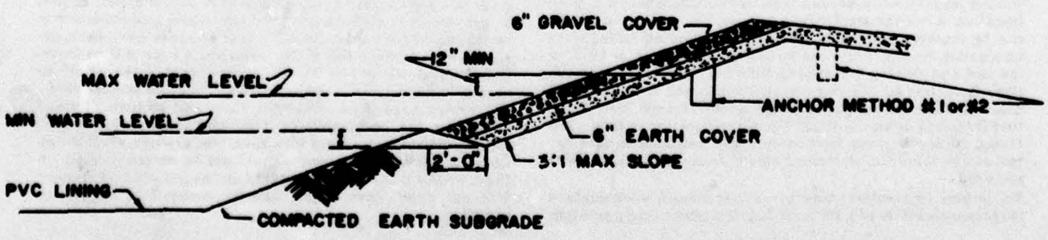
SEAL TO PIPE



TYPICAL LAP SPLICE JOINT



EARTH AND GRAVEL COVER - FULL SLOPES



EARTH AND GRAVEL COVER - PARTIAL SLOPES

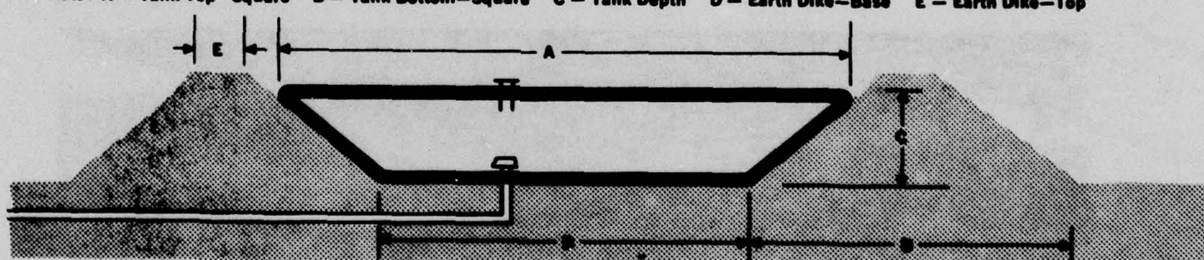
APPENDIX J

FIRESTONE FABRITANK LINER[1]

EMBANKMENT FABRITANK SIZES* AND DATA

NOMINAL CAPACITY (GALS.)	TANK DIMENS. (FT.)			DIKE DIMENS.		AVERAGE EARTH DIKE (CU. YDS.)	TANK NET WEIGHT (LBS.) (APPROXIMATE)
	A	B	C	D	E		
25,000	33.2	15.2	6	22.5	1.5	549	836
50,000	41.5	17.5	8	29.0	2.0	1045	1,286
100,000	52.4	22.4	10	35.5	2.5	1855	2,045
200,000	66.4	30.4	12	42.0	3.0	3137	3,269
300,000	77.7	41.7	12	42.0	3.0	3628	4,414
400,000	87.2	51.2	12	42.0	3.0	4041	5,506
500,000	95.6	59.6	12	42.0	3.0	4402	6,563
600,000	103.1	67.1	12	42.0	3.0	4728	7,597
700,000	110.0	74.0	12	42.0	3.0	5028	8,615
800,000	116.5	80.5	12	42.0	3.0	5307	9,617
900,000	122.5	86.5	12	42.0	3.0	5568	10,609
1,000,000	128.2	92.2	12	42.0	3.0	5816	11,593

Note: A — Tank Top—Square B — Tank Bottom—Square C — Tank Depth D — Earth Dike—Base E — Earth Dike—Top



EMBANKMENT AND TANK CROSS SECTION

All tanks are oversize 10%.
***Other sizes available on request.**

NOTE:
Tank dimensions A, B & C are shown to illustrate standard available sizes and capacities. **Embankment dimensions D & E and average earth dike quantities are to be considered as schematic illustrations only. Since structural characteristics of soil vary, it is important that the embankment design be determined by a qualified civil or consulting engineer.**

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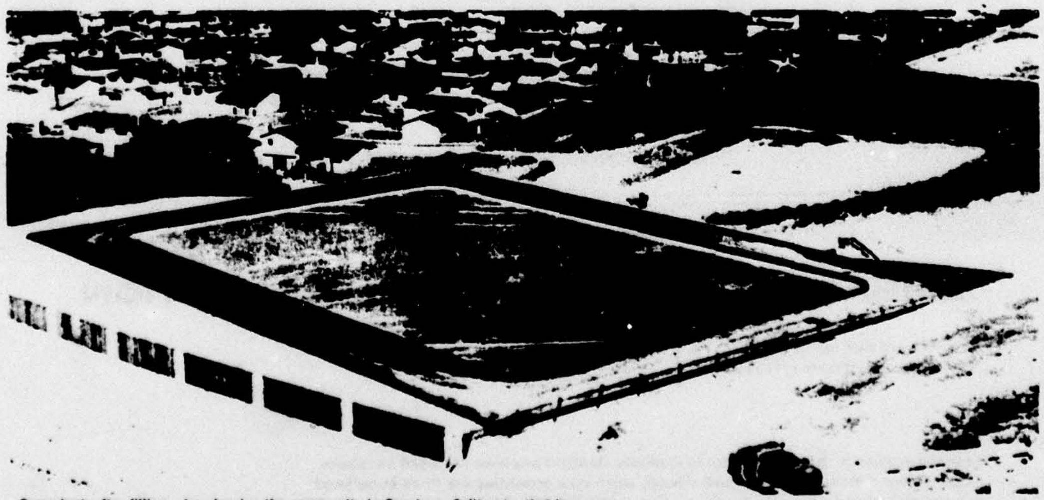
[1] Courtesy of Firestone Coated Fabricks Company, Magnolia, Arkansas.

TYPICAL INSTALLATIONS

One-million-gallon Fabritank for domestic water service, prior to filling.



Same tank after filling, also showing the community in San Jose, California, that it serves.

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